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Problem-Based Learning in the Context of Mathematical Critical Thinking: A Bibliometric Trend Analysis

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Abstract: This study explores the integration of Problem-Based Learning (PBL) in mathematics education by mapping research trends on mathematical critical thinking through a bibliometric analysis of 791 Scopus-indexed publications from 2021 to April 2025. Employing a five-stage bibliometric protocol and VOSviewer software, the analysis visualizes keyword co-occurrence, research clusters, and networks among authors, institutions, and countries. The findings reveal a consistent increase in research interest, with a publication peak in 2024, reflecting the growing recognition of PBL as an effective approach to cultivating higher-order thinking skills. Indonesia emerged as the most productive country, with significant contributions from scholars such as Zubaidah S. and institutions like Universitas Negeri Malang and Universitas Negeri Surabaya. Dominant keywords include "problem-based learning" and "critical thinking", which are strongly associated with other active learning strategies such as project-based learning, flipped classrooms, and collaborative learning. Importantly, the most influential articles predominantly originate from medical and nursing education, underscoring the interdisciplinary potential of PBL. This finding offers valuable insight for mathematics education researchers to adapt evidence-based approaches from other disciplines to strengthen theoretical and practical frameworks in their field. The study underscores the relevance of PBL in addressing 21st-century educational challenges and identifies potential research gaps in areas such as early mathematics education and qualitative approaches. The study not only highlights global engagement with PBL as a 21st-century learning model but also provides a roadmap for future investigations into unexplored areas such as early-grade mathematics education, qualitative methods, and digital PBL supported by artificial intelligence. By bridging pedagogical insights across disciplines, this research encourages more integrative, innovative, and impactful practices in advancing critical thinking through mathematics.

Keywords: problem-based learning, critical thinking, bibliometric analysis, mathematics education, VOSviewer.

▪ INTRODUCTION

The development of science and technology in the era of the industrial revolution 4.0 requires a transformation in the world of education, especially in developing 21st-century competencies (Arsyad, Lestari, Sari, & Rohman, 2023; Chistyakov et al., 2023; Limaymanta, Apaza-Tapia, Vidal, & Gregorio-Chaviano, 2021; Wei, Lin, & Chen, 2023). One of the competencies that has become a major concern in learning this century is the ability to think critically (Dessie, Gebeyehu, & Eshetu, 2023; Mairing, 2021; Pramasdyahsari et al., 2023). Critical thinking skills are an individual's ability to analyze information, evaluate arguments, and make logical and evidence-based decisions (Letchumanan, Husain, Ayub, Kamaruddin, & Zulkifli, 2023; Robeva & Jungck, 2023; Sauter et al., 2022). In the context of mathematics learning, critical thinking is not just an additional skill, but rather the core of a deep and reflective mathematical thinking process (Caratozzolo, Lara-Prieto, Hosseini, & Membrillo-Hernández, 2022; Gallardo-Alba, Grüning, & Serrano-Solano, 2021). Critical thinking skills are important to equip students to solve complex problems, understand abstract concepts, and relate mathematical

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knowledge to real life (Marthaliakirana, Suwono, Saefi, & Gofur, 2022; Rézio, Andrade, & Teodoro, 2022; Sakamaki, Taguri, Nishiuchi, Akimoto, & Koizumi, 2022).

However, the reality of mathematics learning at various levels of education still shows a strong tendency towards conventional and procedural approaches, where teachers dominate the learning process and students become passive recipients of information (Adamczyk, Eadkhong, & Sirisathitkul, 2025; Khurma & El Zein, 2024; Rott, 2021; Youssef, 2024). This approach can not provide sufficient opportunity for students to develop their critical thinking skills optimally (Moreau & Wiebels, 2023; Purnomo, Nabillah, Aziz, & Widodo, 2024; Shongwe, 2024).Therefore, innovative learning models that can create meaningful learning experiences and empower students in their thinking process are needed (Gupta, Bhatt, Mathur, Badge, & Sharma, 2024; Morard, Sanchez, & Bonnat, 2023; Utami & Pramudiani, 2024).

One of the learning models that has gained widespread attention in the last two decades is Problem-Based Learning (PBL) (Ahmad, Akhsani, & Mohamed, 2023; English, 2023; Larkin & Lowrie, 2023; Monteleone, Miller, & Warren, 2023). The PBL learning model emphasizes the presentation of authentic problems as a learning stimulus, where students are encouraged to collaborate, explore knowledge independently, and build understanding through the problem-solving process (Marthaliakirana et al., 2022; Rézio et al., 2022; Sakamaki et al., 2022). PBL is designed to shape higher-order thinking skills as it encourages students to analyze information, examine alternative solutions, and develop logical arguments (Kurniati & Sutiarso, 2021). Several empirical studies have shown that the implementation of PBL in mathematics learning has a positive impact on the development of students' mathematical critical thinking skills (Arsyad et al., 2023; Monteleone et al., 2023; Romero-Esquinas, Muñoz-González, Vega-Gea, & Hidalgo-Ariza, 2022).

Along with the increasing interest in the application of PBL in mathematics education, the number of scientific publications that discuss the relationship between PBL and critical thinking skills continues to grow (Kudo et al., 2025; Marthaliakirana et al., 2022). This creates a need for a thorough understanding of how trends and directions in research on this topic are shaping up (Drobnič Vidic, 2023; Foley, Budhathoki, Thapa, & Aryal, 2023; Youssef, 2024). However, studies that map the research landscape in a systematic and structured manner using quantitative approaches are still relatively limited (Barnabè, Armenia, Nazir, & Pompei, 2023; Romero-Esquinas et al., 2022). Without such a map, there is a risk of research redundancy, limited interdisciplinary collaboration, and delayed identification of emerging trends or promising research gaps. This underscores the urgency of conducting a comprehensive bibliometric analysis to guide future inquiry in a more strategic and informed direction (Adamczyk et al., 2025; Barradas, Lencastre, Soares, & Valente, 2024; De Angeli et al., 2021; Gallardo-Alba et al., 2021).

To address these needs, bibliometric analysis is a relevant and strategic approach. It allows researchers to evaluate publication trends, annual distribution, keyword networks, the most productive authors or institutions, and patterns of collaboration and citation within a specific research domain. Tools such as VOSviewer enable the visualization of these patterns, providing a comprehensive overview of the structure, evolution, and direction of research fields. This approach has been widely recognized as effective and has been successfully applied in various areas of educational research. For instance, Zakaria & Mahat (2024) conducted a bibliometric analysis to map global trends

in gamification research in education, revealing how interest in gamified learning has evolved and identifying key themes, authors, and regions contributing to the field. Similarly, Limaymanta et al. (2021) analyzed two decades of research on the flipped classroom, providing valuable insights into publication growth, conceptual structures, and underexplored topics that require further investigation. These examples demonstrate that bibliometric analysis is a proven and valuable method not only for synthesizing large volumes of literature but also for identifying knowledge gaps and guiding future research agendas.

Based on this background, this article aims to conduct a bibliometric analysis of scientific publications that examine the relationship between Problem-Based Learning and mathematical critical thinking skills. The main focus of this study is to map publication trends in terms of annual number and distribution, analyze dominant keywords, identify the most productive authors, institutions, and countries, as well as the most influential articles in the growing research. It is hoped that the results of this study can serve as an important foundation for researchers, educational practitioners, and policymakers in designing more innovative mathematics learning development based on strong empirical evidence.

▪ METHOD

Research Design

This study employs a descriptive bibliometric research design aimed at mapping the research landscape surrounding Problem-Based Learning (PBL) and mathematical critical thinking. Bibliometric analysis was selected as the methodological framework because it enables the identification of publication trends, collaborative patterns, and conceptual structures within a large volume of scientific literature. The approach is exploratory and quantitative, focusing on metadata from peer-reviewed articles indexed in Scopus. The globally recognized Scopus platform is ideal for bibliometric research (Limaymanta et al., 2021). Scopus's broad range of disciplines ensures complete coverage for analyzing the landscape of problem-based learning models in the context of mathematical critical thinking (Gontier, Surace, Delvendahl, Müller, & Pfister, 2023; Sauter et al., 2022; Wei et al., 2023). The bibliometric analysis procedure used in this study follows a five-stage model consisting of: Search keyword assignment, Initial search results, Refinement of search results, Relevance screening, and Compilation and Analysis.

Search Strategy

The data collection process was conducted in May 2025 using the Scopus platform. To narrow the scope to research relevant to mathematics education, the keywords “problem-based learning”, “critical thinking”, and “mathematics” were used in combination. The exact search string was: (TITLE-ABS-KEY("problem-based learning") AND TITLE-ABS-KEY("critical thinking") AND TITLE-ABS-KEY("mathematics")) AND (PUBYEAR > 2020 AND PUBYEAR < 2026) AND (DOCTYPE("ar")). The publication year range from 2021 to April 2025 was deliberately selected to capture recent developments in post-pandemic education. This period reflects a phase of major pedagogical transformation globally, especially in how educators adapted and restructured learning models to emphasize critical thinking and student-centered approaches like PBL. In addition, this timeframe includes national education reforms in

productive countries such as Indonesia, which have prioritized 21st-century skills and digital pedagogies, making it particularly relevant for understanding current research directions.

Inclusion and Exclusion Criteria

The inclusion criteria were: (1) research articles published between 2021 and April 2025; (2) articles written in English; (3) articles containing all three keywords: 'problem-based learning', 'critical thinking', and 'mathematics'; and (4) articles focused on educational contexts. The exclusion criteria included: (1) duplicates, (2) non-research articles (e.g., reviews, editorials, conference proceedings), (3) articles outside the date range, and (4) articles not explicitly related to mathematics education, which were removed via manual title and journal screening.

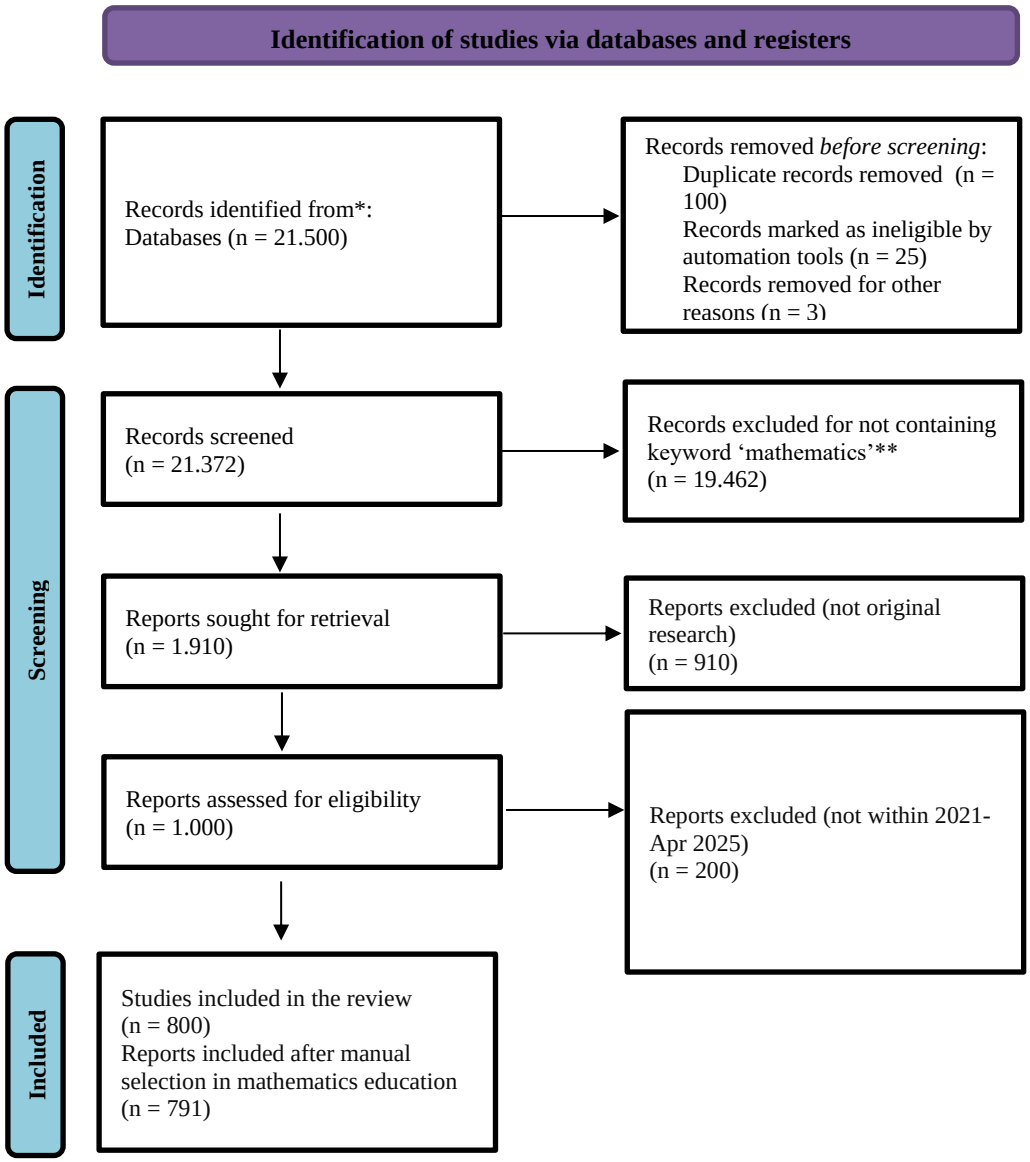

Figure 1. Research flow chart

Data Analysis

All selected articles were exported in CSV format from Scopus and processed using VOSviewer version 1.6.21. Several types of bibliometric analysis were conducted, including: author keyword co-occurrence analysis to identify frequently used terms and map thematic clusters, country-level co-authorship analysis to explore patterns of international collaboration, and bibliographic coupling to examine shared reference usage and identify conceptual linkages among publications. For the co-occurrence analysis, the unit of analysis was set to author keywords, with a minimum threshold of 5 occurrences. Out of 2,378 unique keywords, 47 met the threshold and were included in the final mapping. The resulting bibliometric map revealed four major clusters representing dominant themes: digital learning and engineering education (red), nursing education and skills development (green), medical education and methodological validation (blue), and socio-demographic perspectives in PBL (yellow). The co-authorship analysis by country indicated limited international collaboration, with most publications concentrated in regionally siloed networks. Although this study did not include co-citation analysis, such an approach is recommended for future research, as it can uncover the intellectual foundations of the field by identifying the most frequently co-cited authors and documents. This would complement the current analysis by providing deeper insights into the theoretical underpinnings of PBL and critical thinking studies. Integrating co-citation and institutional co-authorship analyses in future studies is likely to enrich understanding of both the evolution and interconnectivity of scholarly contributions across disciplines and borders.

Due to the large number of preliminary records and the thematic focus of this study, the screening process was limited to publication titles only, rather than including full-text or abstract reviews. While this strategy improved efficiency and ensured topical clarity, it also introduced a significant source of potential bias. Relevant studies whose key concepts, such as “problem-based learning” or “critical thinking in mathematics” appear only in the abstract or body text may have been inadvertently excluded. This limitation can potentially underestimate the contribution of specific fields, especially interdisciplinary studies or research framed using alternative terminology. As a result, the research map produced may not fully represent the complete landscape of scholarship on this topic. This methodological choice, while consistent with prior bibliometric practices (Zakaria & Mahat, 2024), should be interpreted with caution. Future studies are encouraged to consider more inclusive screening methods (e.g., title + abstract review) to enhance representativeness and reduce topical omission.

▪ RESULT AND DISSCUSSION

Based on the results of bibliometric visualization generated with VOSviewer, the following findings were obtained:

Research Publication Trends

Research articles on Problem-Based Learning in the context of mathematical critical thinking from 2021 to April 2025 are shown in Figure 2. Based on the data, we can observe fluctuations in the number of publications over these five years. In 2021, there were 161 publications on this topic. This number decreased in 2022 to 118 publications, which is likely due to the transition or shift in research focus post-COVID-19 pandemic. However, in 2023, there was an increase to 175 publications, which shows

a return of interest in developing problem-based learning and critical thinking skills in mathematics. This trend peaked in 2024 with the highest number of publications at 252 articles. This significant spike can be interpreted as a result of the growing attention to innovative learning approaches in mathematics education, particularly following major academic events and publications. For instance, the 15th International Congress on Mathematical Education (ICME-15), held in 2024, emphasized the role of critical thinking and problem-based learning in 21st-century classrooms. Additionally, several Scopus-indexed journals, such as Thinking Skills and Creativity and Journal of Mathematics Education, published special issues in 2024 focusing on active learning, which likely contributed to the surge in scholarly output on this topic. However, in 2025 until April, the number of publications was recorded at only 85 articles. This figure cannot be used as a final representation for the year because it is still in progress, and it may increase along with the remaining publication time until the end of the year. Overall, the publication trend shows an increasing interest in Problem-Based Learning research in the context of mathematical critical thinking, with the highest peak in 2024. This reflects the urgency and relevance of the theme in the global mathematics education discourse.

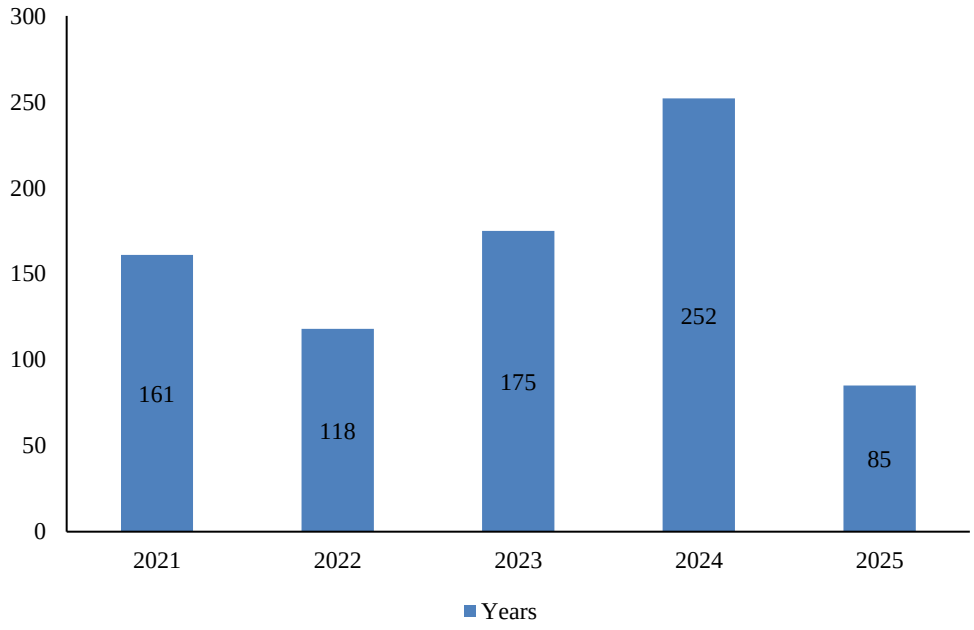

Figure 2. Chronological distribution of research articles related to problem-based learning in the context of mathematical critical thinking in scopus (from 2021 to April 2025)

Keyword Analysis

Based on the analysis of the Author Keywords column of Scopus-indexed articles on Problem-Based Learning (PBL) in the context of mathematical critical thinking, the results show that there are several dominant keywords that researchers often use. The most frequent keyword was “problem-based learning” with a frequency of 218, followed by “critical thinking” 142 times. This shows that the main focus of these articles is indeed on problem-based learning approaches that are directly related to the development of

critical thinking skills. In addition, several keywords related to other learning approaches also appeared with high frequency, such as "project-based learning" (62), "active learning" (53), "flipped classroom" (22), and "collaborative learning" (20). This reflects the tendency of researchers to associate PBL with various active learning strategies designed to promote students' deep engagement and understanding.

In addition the appearance of keywords such as "nursing education", "engineering education", and "medical education" shows that the application of PBL and the development of critical thinking is not only limited to mathematics education, but has also been extended to various disciplines, especially those that demand real solving of complex problems. The presence of keywords such as "critical thinking skills", "learning outcomes", and "problem solving" also confirms that the main purpose of implementing PBL is to improve students' higher-order thinking skills and learning outcomes. Overall, this analysis shows that research on PBL in relation to mathematical critical thinking has a wide scope, high relevance, and close linkages with various other active learning approaches, and is applied in various educational contexts.

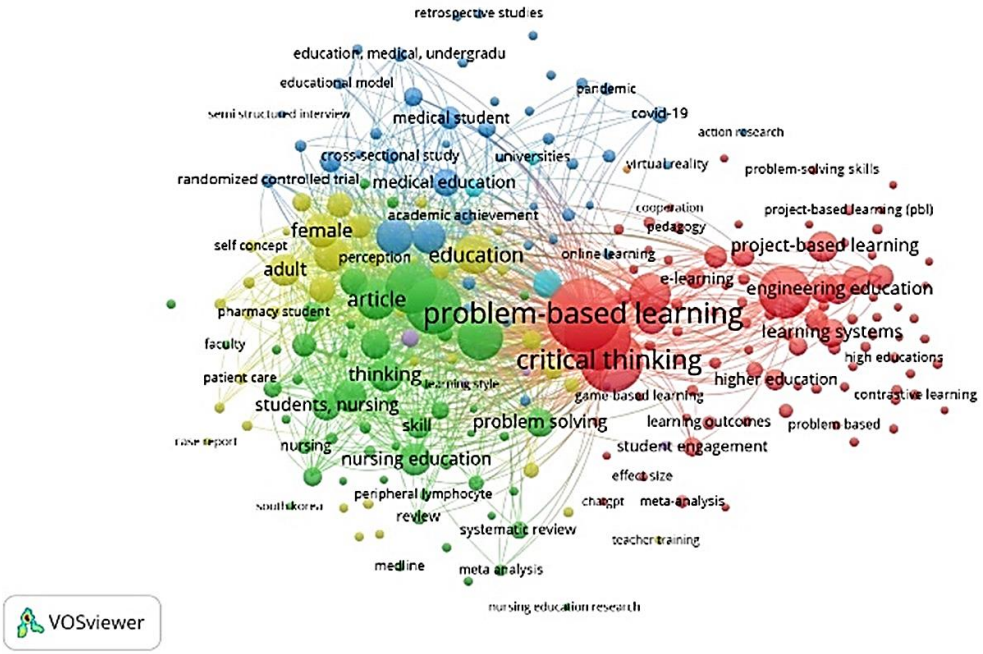

Figure 3. Co-occurrence of author keywords

This visualization divides keywords into different colored clusters that reflect semantic relationships between terms based on frequency of occurrence and co-occurrence in scientific publications. Based on data from VOSviewer, the keywords "problem-based learning" and "critical thinking" appear as the most central terms in the entire network, with total link strength values of 1,256 and 1,072, respectively. Their positions at the center and the dense connections to other keywords indicate their strong relational power across different research themes.

The red cluster focuses on innovative and digital learning approaches, characterized by keywords such as "project-based learning", "engineering education", "e-learning", "student engagement", and "learning outcomes". These terms suggest that this cluster

centers around the integration of PBL to foster critical thinking in higher education through the use of digital technologies and modern pedagogical frameworks.

The green cluster is dominated by keywords like "nursing education", "student nursing", "skills", "problem solving", and "pharmacy student". This cluster reflects how PBL is applied in healthcare education, emphasizing practical, skill-based learning and critical thinking in clinical settings. The strong co-occurrence between "nursing education" and terms like "problem solving" arises from the nature of nursing education, which heavily emphasizes hands-on scenarios, patient care, and the development of professional reasoning.

The blue cluster centers on "medical education", "medical student", "randomized controlled trial", "cross-sectional study", and "academic achievement". This indicates that research in this cluster often applies experimental or quantitative methodologies to test the effectiveness of PBL in structured health education environments. The dominance of methodological terms reflects the evidence-based culture in medical education research.

The yellow cluster includes terms such as "female", "adult", "self-concept", "perception", and "teacher training", suggesting a focus on psychosocial and demographic aspects of PBL. Studies in this cluster likely explore how individual characteristics (e.g., gender, age, or personal beliefs) influence the implementation and impact of PBL on learning outcomes.

Additionally, overlay visualization from VOSviewer highlights emerging keywords such as "artificial intelligence", "digital learning", "virtual reality", and "online learning", which appear in lighter colors (yellow), indicating that these are more recent research focuses. This suggests an increasing trend in integrating technology-enhanced PBL models, especially in the post-pandemic context.

Overall, the structure of this visualization reflects not only thematic clustering but also methodological and disciplinary distinctions. The connections show that research on PBL and critical thinking is multi-dimensional, spanning pedagogical innovations, domain-specific applications (especially in medicine and engineering), research methodologies, and socio-psychological factors.

This analysis is very useful for mapping the research landscape, identifying trends, and highlighting research gaps that can still be explored. Among these gaps, two areas stand out: elementary mathematics education and the use of qualitative approaches. Research in early-grade mathematics is crucial, as foundational thinking and problem-solving habits begin to form during this stage. Meanwhile, qualitative studies are essential for uncovering how students develop critical thinking through PBL, as well as capturing the subjective experiences of learners and the practical challenges faced by teachers in classroom implementation. Unlike quantitative data, which focuses on outcomes and general patterns, qualitative inquiry offers rich, contextual insights into the processes, interactions, and perceptions involved in PBL-based instruction. Addressing these gaps would deepen our understanding of how PBL works in diverse educational settings and provide more comprehensive evidence to inform teaching practice.

Productive Authors, Institutions, and Countries

Based on data analysis of publications indexed in Scopus related to Problem-Based Learning (PBL) and mathematical critical thinking, several authors have shown high

productivity in this field. Among them, Zubaidah and Juandi occupy the top position with seven articles each, followed by Chen, Hegade, and Shettar with five publications each. Analysis of the co-authorship map generated using VOSviewer indicates that several of these authors, particularly Zubaidah and Juandi, are actively involved in collaborative research networks. However, the overall co-authorship network shows that many productive authors tend to publish independently or in small, localized groups, suggesting that wider international collaboration in this domain is still limited. In terms of institutions, KLE Technological University (India), State University of Malang, and State University of Surabaya (both in Indonesia) emerged as the most productive institutions, each with three publications. Other notable contributors include Hyderabad Institute of Technology and Management, Jakarta State University, and Universiti Putra Malaysia, indicating a growing regional focus on PBL and critical thinking development in Southeast and South Asia. These institutions appear as central nodes in institutional collaboration maps, showing medium levels of inter-institutional linkage.

Regarding influential articles, the identification of most cited publications was based on citation count not co-citation analysis, which is a different bibliometric technique. The top-cited articles in this dataset mainly originate from the fields of medical and nursing education, indicating that impactful PBL related research has been particularly prominent in health-related disciplines. students.

Geographically, Indonesia is the most productive country in publishing scientific papers on Problem-Based Learning (PBL) and mathematical critical thinking, with a total of 303 publications. This indicates that the development of innovative learning methods and the enhancement of critical thinking skills have become a significant focus among Indonesian academics and educators. Following Indonesia are the United States (243 publications), China (138), India (111), and Malaysia (83), with Asian countries showing increased engagement in 21st-century pedagogy.

However, an interesting gap emerges: none of the ten most cited articles in this field have first authors affiliated with Indonesian institutions, despite Indonesia's high output. This discrepancy may be attributed to several possible factors. First, research conducted in Indonesia may primarily focus on local classroom contexts, such as small-scale implementations or action research, which tend to be less frequently cited than large-scale empirical studies or systematic reviews. Second, there may be language barriers or limited access to high-impact international journals, which can affect both visibility and citation performance. Third, many Indonesian publications may prioritize national or regional relevance over global theoretical contributions, which can result in lower international recognition.

This suggests the need for increased international collaboration, enhanced methodological rigor, and broader dissemination strategies to elevate the global impact of Indonesian research. Strengthening the quality and visibility of Indonesian scholarship can help bridge this gap and contribute more significantly to global discourses on innovative education publications.

Most Influential Articles (Based on Number of Citations)

Based on the analysis of Scopus-indexed publication data, the most influential articles in the field of Problem-Based Learning (PBL) and mathematical critical thinking were identified based on the highest number of citations. The article with the highest

citations is by Foo et al., entitled "A comparative study regarding distance learning and the conventional face-to-face approach", published in 2021 in the journal BMC Medical Education, with a total of 95 citations. This article compares the effectiveness of distance and face-to-face learning and highlights the contribution of problem-based approaches to learning outcomes, especially in the context of medical education.

Second place goes to the article titled "Nursing education in the age of artificial intelligence: Reimagining teaching and learning" by Tam et al., published in 2023 in Nurse Education Today, with 78 citations. This article is highly relevant to the topic of PBL as it explores how active learning approaches, including problem-based learning, are being reimagined in the context of artificial intelligence and digital transformation in nursing education. Another influential article is "Metacognitive Strategies and Development of Critical Thinking" by Rivas et al., published in Frontiers in Psychology (2022), which has 68 citations and emphasizes the role of metacognitive strategies in cultivating students' critical thinking abilities.

The fact that many of the most cited articles originate from medical and nursing education has important implications for mathematics education researchers. These fields have had a longer and more mature engagement with PBL, not only in its classroom implementation but also in rigorous empirical validation, framework development, and assessment tools. As such, mathematics education researchers can and should learn from the methodological sophistication and theoretical robustness found in these disciplines. Integrating lessons from health education research can help elevate the quality, impact, and global relevance of studies on PBL in mathematics contexts. This cross-disciplinary learning opens opportunities to adapt existing validated instruments, research designs (e.g., longitudinal or mixed methods), and evidence-based best practices for mathematics classrooms.

Another article that also shows high influence is Dong et al.'s "The effects of flipped classroom characterized by PBL on students' learning outcomes" (2021), with 63 citations, as well as an article by Bucklin et al. on active learning strategies, which also received 63 citations. Both articles reinforce PBL's position as an approach capable of improving learning outcomes and higher-order thinking skills in education.

Other articles that made the top ten list involved studies on team-based learning, reflective thinking, project-based learning, and a systematic review of PBL in STEM fields, showing that the topic of critical thinking and PBL has been adopted in various disciplines and approaches. These articles were published between 2021 and 2023 in internationally reputable journals such as Nurse Education Today, Thinking Skills and Creativity, and Educational Psychology Review. The high number of citations of these articles indicates that the publications have made substantial contributions to the development of theory and practice in problem-based education and the strengthening of thinking.

Table 1. Influential articles

No.	Article Title	Lead Author	Tahun	Number of Citations	Journal/Source
1	*A comparative study regarding distance learning and the*	Foo et al.	2021	**95**	BMC Medical Education

	conventional face-to-face approach				
2	*Nursing education in the age of artificial intelligence: Reimagining teaching and learning*	Tam et al.	2023	**78**	Nurse Education Today
3	*Metacognitive Strategies and Development of Critical Thinking*	Rivas et al.	2022	**68**	Frontiers in Psychology
4	*The effects of the flipped classroom characterized by PBL on students' learning outcomes*	Dong et al.	2021	**63**	Nurse Education Today
5	*Making it stick: Use of active learning strategies in medical education*	Bucklin et al.	2021	**63**	BMC Medical Education
6	*The effectiveness of team-based learning in nursing education*	Alberti et al.	2021	**62**	Nurse Education Today
7	*The Effect of Problem-Based Learning Method Supported by Reflective Thinking Activities*	Hursen	2021	**59**	Technology, Knowledge, and Learning
8	*A cultural perspective to project-based learning in higher education*	Barak & Yuan	2021	**57**	Thinking Skills and Creativity
9	*Systematic review of problem-based learning research trends in STEM education*	Anggraeni et al.	2023	**43**	Thinking Skills and Creativity
10	*Situating Higher-Order, Critical, and Critical-Reflective Thinking in PBL*	Loyens et al.	2023	**42**	Educational Psychology Review

▪ CONCLUSION

This study successfully mapped the dynamics and development of research related to Problem-Based Learning (PBL) in the context of mathematical critical thinking during the period from 2021 to April 2025 based on publications indexed in Scopus. In terms of annual number and distribution, a significant upward trend in publications was found, with the peak occurring in 2024. This surge reflects the increasing awareness and urgency of implementing innovative learning approaches such as PBL to meet the challenges of 21st-century learning. Analysis of keywords also shows that "problem-based learning" and "critical thinking" are central to studies that are semantically connected to various active pedagogical approaches such as project-based learning, flipped classroom, and collaborative learning. This finding indicates that PBL does not stand alone, but is part of a holistic and adaptive learning ecosystem.

Among the most productive authors, institutions, and countries shows that significant contributions come from the Asian region, especially Indonesia, which

occupies the top position in the number of publications. This shows that Indonesia is on the path of educational transformation through the adoption of problem-based learning approaches that prioritize strengthening critical thinking skills. At the individual level, authors such as Zubaidah and Juandi are important actors in this research map, while in terms of institutions, Malang State University and Surabaya State University are the centers of research productivity. In addition, the most influential articles based on the number of citations show that the PBL approach is widely applied in various disciplines such as medical education, nursing, and engineering, with several articles becoming important references in the discourse of developing higher-order thinking skills.

While many studies have been conducted, this research also reveals that there is still room for exploration. Some research clusters show a tendency to focus on specific fields such as medical and nursing education, so there are still opportunities to expand the study to other fields, especially mathematics education at the primary and secondary levels. In addition, quantitative approaches dominate existing research methods, whereas combining with qualitative or mixed-method approaches has the potential to provide a more complete understanding of the dynamics of PBL implementation and its influence on the formation of critical thinking. In the future, further research can be directed to explore the effectiveness of PBL models in the context of digital learning, the role of artificial intelligence in supporting PBL personalization, and longitudinal evaluation of the impact of PBL on learning outcomes and student character development. Thus, the results of this study not only describe the existing research landscape but also provide an important foundation for the development of further research directions that are more interdisciplinary, contextual, and based on the future needs of education.

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