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Bibliometric Analysis of Publications on Problem-Based Learning and Critical Thinking Skills in Mathematics Education

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Abstract

This study aims to analyze the development of scientific publications on Problem-Based Learning (PBL) and critical thinking skills in mathematics education through a bibliometric approach. This research employed a quantitative descriptive method, with data retrieved from the Scopus database using the keywords"problem-based learning","critical thinking", and "mathematics education" within the period 2013–2024. Data were analyzed using VOSviewer and Biblioshiny to identify publication trends, keyword clusters, and thematic research directions. The results indicate a significant increase in the number of publications, particularly after 2018, with dominant themes are such as higher-order thinking skills, STEM education, and technology integration in PBL implementation. Keyword analysis reveals strong interconnections among the concepts of problem-solving, critical thinking, and context-based mathematics learning in digital settings. This study also identifies future research opportunities in integrating PBL with artificial intelligence, adaptive learning, and teacher professional development. The findings conclude that research on PBL in mathematics education is progressing toward an interdisciplinary and technology-based paradigm. The implication suggests that future studies should develop empirical and design-based research approaches to strengthen the implementation of PBL that sustainably fosters critical thinking skills in the era of digital learning.

Keywords: *: Problem-Based Learning, Critical Thinking, Mathematics Education, Bibliometric Analysis.*

INTRODUCTION

Mathematics education in the 21st century demands that students not only possess computational proficiency but also develop critical, analytical, and reflective thinking skills in solving problems (Bawadi et al., 2023; Ritmayanti et al., 2025). However, teaching practices across various educational levels still tend to emphasize procedural mastery and rote memorization of formulas rather than higher-order thinking skills. Consequently, students often face difficulties in connecting mathematical concepts to real-world situations and exhibit a low level of critical thinking ability

(Kholid et al., 2024; Utami, 2025). In this context, Problem-Based Learning (PBL) emerges as a pedagogical strategy that places real-world problems as the starting point of instruction to encourage deep and collaborative thinking (Kholid, 2018; Kurniawan et al., 2023; Sholikhah et al., 2023). Along with the growing emphasis on the development of higher-order thinking skills, there is a pressing need to understand the extent to which PBL has been examined and implemented in mathematics education.

Over the past two decades, scholarly literature on PBL and critical thinking skills in mathematics education has grown rapidly across different countries. Nevertheless, despite the abundance of empirical studies, there remains a lack of a comprehensive map that quantitatively and visually illustrates the direction, patterns, and thematic interconnections in this field. The bibliometric approach enables researchers to identify publication trends, scholarly collaborations, and dominant research topics that shape the scientific structure of this domain (Karim, 2021; Wahyuni et al., 2024). Through such analysis, it becomes possible to trace how knowledge construction on PBL and critical thinking in mathematics has evolved over time. Therefore, this study holds strong rationale to fill the existing gap in the literature by systematically mapping the global dynamics of research on this topic.

The urgency of implementing Problem-Based Learning (PBL) and developing critical thinking skills in elementary mathematics education lies in the need to establish a strong cognitive foundation from an early age, in accordance with the demands of 21st-century literacy. At the elementary level, students must not only understand mathematical concepts procedurally but also be able to analyze situations, evaluate information, and solve problems reflectively and creatively. PBL provides an authentic and contextual learning environment that enables students to construct mathematical understanding through direct experience and independent inquiry, thereby stimulates higher-order thinking processes (Phasa, 2020). Methodologically, the urgency of this research arises from gaps in the existing literature, which indicate that the implementation of PBL in elementary schools remains limited and has not been extensively examined, particularly in terms of its effectiveness in fostering critical thinking within a mathematics context that is continually evolving in response to digital transformation. Therefore, research that strengthens empirical evidence on the integration of PBL and critical thinking development at the elementary level is essential for providing a scientific basis for instructional innovation, curriculum development, and teacher professional growth aimed at improving the quality of mathematics education at the foundational stage.

This study aims to comprehensively analyze the development of research on the implementation of Problem-Based Learning (PBL) and the enhancement of critical thinking skills in mathematics education through a bibliometric approach. Specifically, this study focuses on identifying publication trends, dominant themes, and key research keywords over the past decade, as well as exploring future directions and research opportunities. The analysis is expected to provide an empirical overview of how the body of knowledge related to PBL and critical thinking in mathematics education has evolved over time. Moreover, this study seeks to uncover emerging research trajectories relevant to 21st-century mathematics learning needs, including digital technology integration and interdisciplinary approaches. Thus, the findings of this study contribute to strengthening the theoretical and methodological foundations for researchers and educators seeking to develop innovative problem-based learning strategies that foster students' critical thinking skills.

The novelty of this research lies in its systematic effort that mapping the global scientific landscape connecting two pivotal concepts—Problem-Based Learning and critical thinking—specifically within the context of mathematics education, using a bibliometric approach that has rarely been applied before. Most previous studies have focused solely on assessing the effectiveness of PBL through classroom experiments or systematic reviews without examining the patterns of scholarly relationships, thematic trends, and citation influence on a global scale. This study presents visual mapping and quantitative analysis demonstrating how research on PBL and critical thinking in mathematics has evolved, interacted, and formed distinct thematic clusters. This approach offers new insights into the dynamics of knowledge development in mathematics education and provides a strategic perspective for future research directions.

METHODS

This study employed a bibliometric approach with a quantitative descriptive design to analyze the development and research trends on Problem-Based Learning (PBL) and critical thinking skills in mathematics education (Fitriyah & Dasari, 2023; Muhammad et al., 2023). The data were retrieved from the Scopus database, selected for its comprehensive and credible coverage of peer-reviewed academic literature. The search strategy used the keywords "problem-based learning" AND "critical thinking" AND "mathematics education" applied to titles, abstracts, and author keywords, covering the publication period from 2013 to 2024. Inclusion criteria consisted of English-

language journal articles that had undergone peer review, whereas conference proceedings, editorials, book chapters, and non-academic publications were excluded. Irrelevant and duplicate documents were removed through a two-stage screening process: an automatic filtering phase using Scopus document tools followed by manual verification to ensure accuracy and relevance.

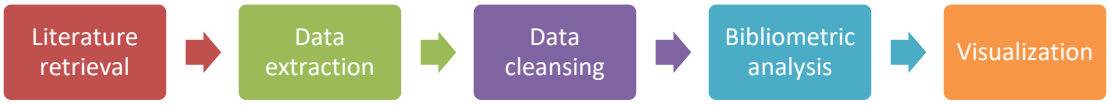


Figure 1. Bibliometric Analysis Process

Data analysis followed a structured workflow consisting of four stages: (1) data extraction, including full metadata download in RIS and CSV formats; (2) data cleaning, which involved removing duplicates, standardizing author names, and harmonizing keyword variations; (3) descriptive bibliometric analysis, where indicators such as annual publication trends, authorship productivity, journal impact, citation patterns, and international collaboration networks were examined; and (4) science mapping, conducted using VOSviewer and Biblioshiny (R-package Bibliometrix) to visualize co-authorship networks, country collaborations, and keyword co-occurrence clusters. Reliability of the dataset was ensured through cross-checking between software outputs and manual verification of metadata consistency (Ab Rashid, 2023; Derviş, 2019; Iriyani et al., 2023).

All visualizations were generated in the form of network maps to identify research clusters, thematic evolution, and dominant conceptual linkages that have emerged over the past decade. The analytical procedures were aligned with the research objectives that systematically tracing how bibliometric indicators reveal publication dynamics, thematic concentrations, and potential research gaps. The resulting interpretations provide a comprehensive understanding about the progression of PBL and critical thinking research in mathematics education, and identify promising directions for future scholarly inquiry. .... of learning media that are appropriate to student characteristics and current learning needs.

RESULTS AND DISCUSSION

To address the objectives of this study, the discussion is organized into three subtopics: (1) annual publication trends, (2) keyword analysis and dominant themes, and (3) future research directions and opportunities, all of which collectively provide a

comprehensive understanding about the dynamics of PBL and critical thinking research within the context of modern mathematics education. This section presents the main findings derived from the bibliometric analysis of scientific publications on Problem-Based Learning (PBL) and critical thinking skills in mathematics education during the 2013–2024 period. The analysis was conducted to reveal patterns of research development, dominant themes, and the direction of scholarly evolution in this field. Data obtained from the Scopus database were processed using VOSviewer and Biblioshiny software to produce visual representations of publication trends, collaboration networks, and conceptual linkages among studies. The results of this analysis not only demonstrate the quantitative growth of publications, but also illustrate the thematic and methodological transformations that have occurred over the past decade.

1. Annual Publication Trends

Based on data retrieved from the Scopus database during the 2013–2024 period, a significant increase was observed in the number of publications discussing Problem-Based Learning (PBL) and critical thinking skills in mathematics education. During the early phase (2013–2016), the number of published articles was relatively low and dispersed across general education journals, indicating that this topic was still exploratory in nature. However, beginning in 2017, there was a sharp rise in publications, coinciding with the adoption of competency-based curricula and the growing emphasis on learning that fosters higher-order thinking skills. This trend continued to rise, reaching its peak in 2022–2023, marked by an increasing number of publications in reputable international journals and greater cross-national research collaboration. This pattern demonstrates that PBL and critical thinking in mathematics education have become a global research focus aligned with the demands of 21st-century education.

The upward trend in publications also correlates with a paradigm shift from teacher-centered to student-centered learning. The emphasis on developing critical thinking has become one of the key indicators of educational quality, particularly since international organizations such as the OECD, through the PISA program, have underscored the importance of mathematical literacy involving analytical and reflective skills (Febriana et al., 2024). Therefore, the increase in research output on this topic reflects an academic response to the growing need for competency-based and critical thinking-oriented educational reform. Furthermore, the expansion of digital learning

platforms and online collaborative research following the COVID-19 pandemic has further broadened the scope of academic inquiry and publication (Janattaka & Adella, 2021; Wibawa, 2021). This phenomenon illustrates how social and technological transformations have strengthened PBL's position as a strategic pedagogical approach in mathematics instruction.

From a temporal perspective, the growth of research in this field can be divided into three phases: the exploratory phase (2013–2016), the expansion phase (2017–2020), and the acceleration phase (2021–2024). During the exploratory phase, studies primarily focused on validating the effectiveness of PBL in basic mathematics learning contexts. In the expansion phase, research themes began to shift toward integrating PBL with educational technology, critical thinking assessment, and implementation across various educational levels. Meanwhile, the acceleration phase saw the emergence of interdisciplinary research combining PBL with collaborative learning models, STEM-based learning, and digital problem-solving environments. Thus, the increasing publication trend not only reflects quantitative growth but also demonstrates thematic and methodological evolution that enriches the body of knowledge on PBL-based mathematics education.

Table 1. Phases of Research Growth on Problem-Based Learning in Mathematics Education

Research Phase	Time Period	Main Research Focus	Thematic and Methodological Characteristics
Exploratory Phase	2013–2016	Validation of PBL effectiveness in basic mathematics learning	Research focused on testing effectiveness and conceptual understanding of PBL; approaches were mostly experimental and early literature reviews.
Expansion Phase	2017–2020	Integration of PBL with learning technologies and critical thinking assessment	Research began to combining PBL with digital media, assessment of critical thinking skills, and implementation at various educational levels.
Acceleration Phase	2021–2024	Interdisciplinary approaches and learning model innovation	Focus shifted to integrating PBL with collaborative learning, STEM-based learning, and digital problem-solving

				environments; employing more complex analytical methods such as bibliometric and mixed-methods approaches.

Overall, the analysis of annual publication trends reveals that research on Problem-Based Learning and critical thinking skills in mathematics education has developed progressively and adaptively in response to changing global educational needs. This dynamic evolution affirms that the development of critical thinking through PBL is no longer merely a pedagogical issue but has become an integral part of the international research agenda for improving the quality of mathematics education. These findings also provide an empirical foundation for future researchers to further explore the relationship between pedagogical innovation, mathematical conceptual mastery, and the strengthening of critical thinking skills in the digital and data-driven era.

Table 2. Summary of Publications on Problem-Based Learning and Critical Thinking Skills in Mathematics Education (2013–2024)

No	Author(s) and Year	Research Focus	Methodology	Key Findings
1	Hmelo-Silver (2013)	Theoretical framework of Problem-Based Learning in mathematics education	Literature Review	PBL strengthened conceptual understanding and enhances students' reasoning and problem-solving processes.
2	Savery & Duffy (2015)	Development of higher-order thinking through Problem-Based Learning	Qualitative Analysis	PBL effectively fostered critical and creative thinking abilities in mathematical problem-solving.
3	Saeed & Ameen (2018)	Implementation of PBL in secondary mathematics education	Experimental Study	Students taught with PBL demonstrated higher engagement, motivation, and achievement compared to traditional instruction.
4	Tan & Neo (2020)	Integration of digital tools into PBL-based	Mixed-Methods	Technology-enhanced PBL increased

		mathematics instruction	Study	collaborative learning, motivation, and understanding of abstract concepts.
5	Ahmed et al. (2021)	Relationship between PBL and critical thinking in mathematics education	Bibliometric Analysis	Global research trends indicated a growing emphasis on critical thinking as a key outcome of PBL.
6	Fitriani & Rahman (2022)	Teacher readiness and challenges in applying PBL	Case Study	Teachers require professional training and pedagogical supported to implement PBL effectively in mathematics classes.
7	Li & Zhang (2023)	Integration of Artificial Intelligence into PBL for mathematics learning	Conceptual Study	AI-supported PBL promoted personalized learning paths and analytical thinking development.
8	Hasanah et al. (2024)	Application of PBL in STEM-based mathematics learning	Quantitative Study	PBL encouraged critical thinking and creativity in solving interdisciplinary STEM problems.

Table 2 presents the summary of publications on Problem-Based Learning (PBL) and critical thinking skills in mathematics education from 2013 to 2024. Based on the eight identified studies, it is evident that the main research focus encompasses strengthening the theoretical framework of PBL, its application in mathematics education, and the integration of technology and artificial intelligence to support problem-based learning. A variety of methodologies were employed—including literature reviews, qualitative analyses, experimental designs, and bibliometric approaches—demonstrating the breadth of academic perspectives used to understand the effectiveness of PBL. The overall findings indicate that PBL enhances students' conceptual understanding, learning motivation, and both critical and creative thinking skills. Moreover, challenges in classroom implementation highlight the importance of teacher training and pedagogical innovation to ensure the successful application of PBL in mathematics learning, particularly in the digital and interdisciplinary context of STEM-based learning.

2. Keyword and Dominant Theme Analysis

The results of the keyword co-occurrence analysis using VOSviewer reveals several major terms that frequently appeared together in publications on Problem-Based Learning (PBL) and critical thinking skills in mathematics education. The most frequently occurring keywords includes problem-based learning, critical thinking, mathematics education, higher-order thinking skills, STEM-based learning, and collaborative learning. The frequency of these keywords indicates that the primary focus of global research remains centered on the implementation of PBL as a strategy for developing higher-order thinking skills within mathematics learning contexts. Additionally, supporting keywords such as digital learning, self-regulated learning, and student engagement are also identified, signifying a thematic expansion toward technology-enhanced learning and the strengthening of learner autonomy. The relationships among these keywords illustrates an increasing integration of pedagogical approaches, cognitive skill development, and digital learning contexts over the past decade.

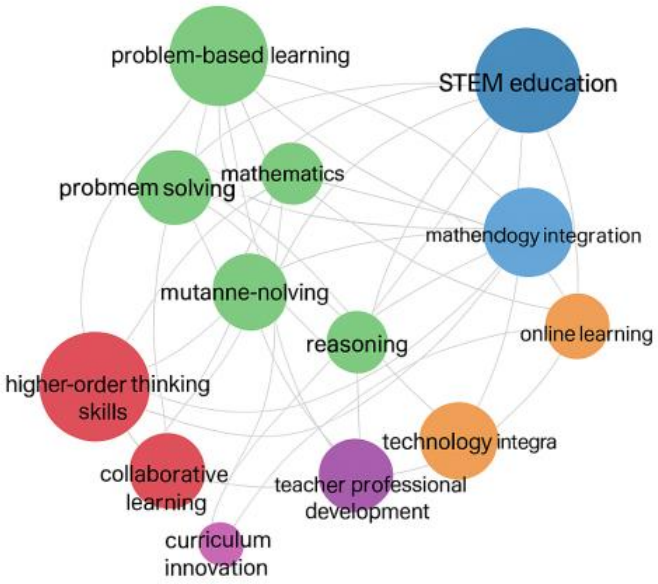


Figure 2. Bibliometric Visualization Results

The visual mapping results reveals that the keyword network is divided into four main clusters, each representing a distinct thematic direction in research. The first cluster, focuses on problem-solving and critical thinking, emphasizing the integration between problem-solving skills and mathematical reasoning development. The second cluster, associates with STEM and higher-order thinking skills, demonstrating a close

relationship between PBL implementation and science-mathematics education. The third cluster highlights the theme of technology integration and online learning, which gained prominence after the COVID-19 pandemic as PBL was adapted to digital learning environments. Meanwhile, the fourth cluster focuses on teacher professional development and curriculum innovation, indicating that PBL research not only examines student learning outcomes but also explores teacher capacity and curriculum policies that support problem-based learning. Together, these four clusters form a complementary research ecosystem and reflect a shift in focus from classroom-level practices toward systemic and policy-oriented approaches.

The analysis also reveals that the term critical thinking has the strongest association with problem-solving and reasoning, indicating a scholarly consensus that critical thinking in mathematics develops through complex and contextual problem-solving processes. This strong connection reinforces the argument that PBL effectively stimulates higher-order thinking processes by requiring students to analyze information, evaluate alternative solutions, and communicate their reasoning logically (Kholid, 2024; Novitasari et al., 2023). Interestingly, recent trends have shown the emergence of new keywords such as artificial intelligence, adaptive learning, and computational thinking, signaling a research shift toward integrating PBL with technology and data-driven learning. This development suggests that studies on PBL and critical thinking in mathematics continue to evolve, adapting to the digital era and the competency demands of the 21st century.

Overall, the findings from the keyword and dominant theme analysis demonstrate that research on Problem-Based Learning and critical thinking skills in mathematics education is no longer monodisciplinary but increasingly interdisciplinary and innovative. The combination of pedagogical, technological, and professional development themes reflects a new, more comprehensive direction in understanding mathematical learning processes. This evolution aligns with global demands for educational practices that foster higher-order literacy and prepare students to address real-world problems (Gradini, 2019; Kholid et al., 2025). Accordingly, these findings underscore the importance of expanding future research toward developing PBL-based mathematics learning models that are adaptive to digital transformation and responsive to contemporary and future educational needs.

3. Future Research Directions and Opportunities

The results of the bibliometric analysis indicate that research on Problem-Based

Learning (PBL) and critical thinking skills in mathematics education continues to evolve thematically in line with technological advancements and the educational demands of the 21st century. Over the past decade, research has been largely dominated by studies examining the effectiveness of PBL in improving learning outcomes and students' critical thinking abilities. However, recent trends reveal a shift toward developing more adaptive, digital, and contextually responsive learning models. The emergence of keywords such as artificial intelligence, gamification, and adaptive learning suggests that future research will likely focus on integrating PBL with intelligent technologies and personalizing the mathematics learning experience. This shift represents a response to global demands for digital literacy and higher-order thinking skills that are increasingly essential in the modern workforce.

In addition, significant research opportunities lie within the domains of teacher professional development and curriculum innovation. Many previous studies have primarily focused on students as the main research subjects, while the role of teachers as designers, facilitators, and evaluators of PBL has not yet been explored in depth. Future studies should investigate how teachers' pedagogical competencies, epistemological foundations, and reflective practices influence the successful implementation of PBL in fostering critical thinking skills. Strengthening action research and design-based research approaches will be highly relevant to uncover innovative teaching practices that adapt PBL to local contexts, learning cultures, and available school resources.

Furthermore, future research holds great potential for expanding the scope of inquiry across disciplines and educational levels. The integration of PBL within STEM-based learning, computational thinking, and environmental mathematics, for instance, may offer new perspectives on how critical thinking can be developed through complex, real-world, and multidimensional contexts. Longitudinal analyses and big data analytics approach also present promising directions for understanding the long-term dynamics of students' critical thinking development. By utilizing advanced bibliometric analyses, future research can map the international scholarly collaborations and identify centers of excellence in PBL-based mathematics education. Overall, these directions and opportunities underscore the importance of transforming mathematics education paradigms towards more collaborative, technology-driven, and holistically competency-oriented approaches suited for the 21st century.

The findings of this study reveal a developmental pattern in research on

Problem-Based Learning (PBL) and critical thinking skills in mathematics education that aligns with, yet simultaneously extends, the insights reported in previous bibliometric and systematic review studies. Earlier research, such as which conducted by Fitriyah & Dasari (2023), Muhammad et al. (2023), Wahyuni et al. (2024) —generally highlighted the growing number of publications on PBL but did not thoroughly examine the integration of critical thinking themes or the emergence of digital technologies within the global research landscape. The present study demonstrates that the evolution of PBL research has expanded beyond pedagogical effectiveness into more interdisciplinary domains, including STEM-based learning, adaptive learning, and the incorporation of artificial intelligence, an emerging trajectory that has received limited attention in earlier analyses. Furthermore, the keyword and thematic cluster analyses in this study confirm previous systematic findings that PBL contributes to the development of higher-order thinking skills while also offering new perspectives on the shifting research focus towards curriculum innovation and teacher professional development.

CONCLUSION

The bibliometric analysis of publications on Problem-Based Learning (PBL) and critical thinking skills in mathematics education reveals a significant upward trend in research over the past decade, with a notable shift in focus from merely testing effectiveness toward integrating problem-based learning models with digital technologies and 21st-century educational contexts. The keyword analysis highlights dominant themes such as higher-order thinking skills, STEM-based learning, and technology-enhanced learning, emphasizing the strong interconnection between PBL and the cultivation of critical thinking as a foundation for developing modern mathematical competencies. Furthermore, future research directions point toward the development of more adaptive, contextual, and interdisciplinary learning models, strengthening the role of teachers as innovators in designing problem-based instruction that aligns with students' needs and global challenges. The implications of these findings underscore the importance of cross-disciplinary research collaboration and the utilization of intelligent technologies to expand the effectiveness of PBL across various educational levels. Therefore, future studies are recommended to deepen empirical investigations through design-based research and longitudinal analyses to gain a comprehensive understanding of how PBL can sustainably foster critical thinking skills within dynamic and future-oriented mathematics learning contexts.

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