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Problem-Based Learning in Mathematics Education: A Bibliometric Analysis on Research Trends, Contributions, and Thematic Analysis from the Dimensions AI Database

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Abstract
Problem-based learning (PBL) has emerged as a prominent student-centred approach that fosters active learning, problem-solving, and higher-order thinking skills (HOTS) in mathematics education. This study aims to examine the trends of PBL research in mathematics education, its scholarly contributions, and its thematic developments within the last decade, 2016-2025. A total of 274 articles related to the research domain were obtained from the Dimensions AI Database using “problem-based learning” and “mathematics education” as the search keywords. The PRISMA Framework was employed to ensure transparency and the completeness of the selection process when reporting the bibliometric review. VOSviewer was used to analyse the publication trends, author contribution, co-occurrence of keywords, as well as thematic clustering. The findings indicate that the PBL research tends to increase steadily, which indicates an increasing of scholarly interest in PBL in mathematics education, especially starting from 2023. Indonesia was the leading contributor in both publication and citation impact in the field of PBL research. However, the findings indicate low global collaboration intensity comparatively, as reflected by limited total link strength. Thematic mapping identifies three interrelated clusters, including (i) the development of critical thinking and problem-solving skills, (ii) mathematical literacy, reasoning, and conceptual competence, and (iii) technological integration and innovative instructions. The study concluded that this research field is consistently increasing. However, it remains structurally fragmented, which requires stronger global collaboration, deeper theoretical integration, and greater emphasis on technology-enhanced pedagogical practices. As a contribution, this study provides a comprehensive overview of the intellectual framework and future directions of PBL research in mathematics education.

Keywords: *bibliometric analysis; mathematics education; problem-based learning; research trends; scholarly contribution, thematic analysis*

I. INTRODUCTION

Problem-Based Learning (PBL) is a well-known teaching and learning method which is recognised for its effectiveness in improving students’ problem-solving skills and abilities in mathematics learning. It encompasses 21st-century skills in promoting students’ higher-order thinking skills (HOTS) by implementing ideas, motivating them to achieve the goals of learning, and enhancing the educational quality as a whole [47]. In addition, PBL has the potential to engage students in a learning environment where problems are presented to encourage active learning that allows them to acquire new knowledge before working on effective solutions [7], [28]. In mathematics, PBL not only helps students develop cognitive abilities, such as creative thinking, problem-solving, and communication skills [12], but it also enhances their critical thinking, fosters innovative ideas, and facilitates mathematical communication through active engagement [50].

Globally, PBL has been acknowledged as a student-centred approach that promotes HOTS, problem-solving skills, inquiry, and collaboration, particularly in mathematics education [4], [35], [52]. Moreover, it has been adopted as an instructional approach in mathematics across Southeast Asian nations, including Indonesia, Singapore, Thailand, and Malaysia [53]. In addition, across levels of education, PBL has also been implemented in various disciplines to help students improve their ability, skills, and performance, including engineering [38], [15], secondary mathematics [46], primary science [37], and primary English [23], [58].

In addition to its expanding pedagogical use, the study of PBL in mathematics education has grown

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significantly. There are several empirical studies that have examined the effectiveness of PBL as an enhancement to the mathematical representation [24], [51], critical thinking [11], and problem-solving skills of students as well as learning outcomes [5], [26], [29]. Current studies have also discussed the potential of ways in which PBL can facilitate the growth of mathematical literacy [31], collaborative learning [10], and student motivation during the learning process in the classroom [6], [18]. The growing number of studies indicates the increasing interest of scholars in learning about the way in which PBL can be efficiently applied to teaching mathematics and the impact it has on the cognitive and conceptual growth of students. However, existing literature highlights the fragmentation across various journals, authors, institutions and geographical locations as the number of studies on PBL in mathematics continues to increase [81], [83], [85], [86].

With the growing research effort, little is known comprehensively about the intellectual structure and growth direction of PBL research in mathematics education. Previous literature has had more emphasis on how effective teaching is or examining PBL interventions in the classroom settings [67], [74], [76], whereas fewer studies have comprehensively identified the broader research groundwork of the discipline [39]-[40], [83]. In that regard, bibliometric analysis can serve as a potential method of studying how a research area has developed by examining publication trends, authorship of documents, and study themes in the literature [20], [39], [83]. In other words, the bibliometric review can provide useful insights into the progress of knowledge in a specific field by determining the powerful contributors, the direction of research, and emerging trends.

Consequently, the primary objective of this study is to provide a comprehensive bibliometric analysis of PBL research in mathematics education through articles indexed in the Dimensions AI database. In particular, the research aims to investigate research trends in publications; examine the contribution made by journals, authors, organisations and countries; identify key research themes; and future research directions in the research field. This study will be guided by the following research questions:

1. What are the major publication trends of PBL research in mathematics education?
2. How do journal sources, authors, institutions, and countries contribute to the research development of PBL practices in mathematics education?
3. What are the key research themes related to PBL practices in mathematics education?
4. What emerging and under-explored research directions of PBL in mathematics education warrant future investigation?

II. LITERATURE REVIEW

PBL was first studied in the late 1960s at McMaster University in Canada to help students develop problem-solving skills through collaborative tasks involving clinical issues in real patients [56]. [56] further indicated that Howard Barrows, a neurologist, was a key figure in the development of PBL. He inverted the conventional learning process by introducing students to patient problems to solve in groups. According to [17], PBL can be defined as a learning method in which problems serve as a starting point for learners to acquire new knowledge, problem-solving serves as a foundation for achieving learning objectives, and it develops competencies and skills applicable to professional practice. Therefore, these problems can be identified by their distinctive characteristics, including missing data or elements that require learners to discover, search for, and explore; they are partially defined and divergent, which means they do not have a single correct answer.

Moreover, PBL is theoretically based on constructivism and inquiry-based learning, whereby student-centred techniques are grounded in offering learners complex real-world problems to develop critical thinking, collaboration, and higher conceptual knowledge [34]. In line with this view, [55] further states that PBL theorises collaborative learning as a critical factor in the co-construction of knowledge and the development of critical thinking skills. In addition, according to [17], six major principles can be applied for effective PBL implementation in knowledge construction and the development of cognitive competencies, including (1) student-centred approach, (2) small group work, (3) teacher acting as facilitator, (4) problem-solving abilities, (5) problem stimulation using real-life problems, and (6) encouragement of self-directed learning. In support of this assertion, a study conducted by [8], who investigated the effectiveness of PBL in mathematics instruction, demonstrated that PBL implementation aligns closely with these principles in supporting mathematics learning outcomes.

Furthermore, the central research focus across the last decade has increasingly emphasised the students' critical thinking and higher-order thinking skills (HOTS). While early literature emphasised the improvement of students' problem-solving abilities in mathematics through PBL [3], [48], recent studies have further expanded their focus to critical thinking and HOTS. For instance, [11] conducted a study on the effectiveness of PBL, with the use of the Baamboozle edugame, to improve students' critical thinking skills. A similar study by [1] also pays attention to improving students' critical thinking by integrating PBL with statistical board teaching aids. Moreover, while [9] highlight the development of HOTS through PBL application, [45] develop learning tools in mathematics based on PBL principles.

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Therefore, this sustained and growing attention positions mathematics, which reflects broader educational priorities, as a fundamental domain for analytical development and cognitive competence through PBL.

III. RESEARCH METHODOLOGY

A. Research Design and Data Source

The bibliometric approach was employed in this study to systematically analyse research trends, patterns, and contributions in the field of PBL in mathematics education. The bibliometric analysis involves significant steps, including data collection from relevant data sources, data refinement, and subjecting the data to various bibliometric methods, which enables the quantitative examination of scholarly publications to identify the intellectual structure and the development of a research domain [20],[27]. In this study, the Dimensions AI was selected as the primary database for its comprehensive indexing of peer-reviewed literature and its accessibility for bibliometric mapping across disciplines. Moreover, it allows performing queries using Domain Specific Language (DSL) through API [40]-[41].

Table 1
Inclusion Criteria for Bibliometric Analysis

Dimensions AI	All
Search keywords	"problem-based learning" AND "mathematics education"
Time period	2016 to 2025
Publication type	Article
Open access	All OA
Field of research	Education

A systematic search strategy was applied to ensure the relevance and reliability of the dataset. As presented in Table 1, the keywords "problem-based learning" AND "mathematics education" were used in searching articles published within the time frame between 2016 and 2025. The inclusion criteria in this study were defined to specifically emphasise the research field while excluding unrelated studies. In this aspect, only journal articles were considered to be included in order to uphold academic quality and consistency. The dataset was also limited to open-access (OA) journal articles in order to make the analysis transparent and reproducible. At the same time, the research area was also limited to the field of education to reduce interdisciplinary noise and to preserve thematic focus. This rigorous screening technique led to a narrow set of data that captures more recent developments, especially post-pandemic shifts, and defines more recent trends in student-centred and problem-oriented learning techniques.

B. Data Collection and Selection

The process of article selection was carried out using the PRISMA framework. As illustrated in Figure 1, the PRISMA flowchart presented a systematic refinement of the recorded article included in this study and guides the selection of studies based on specific inclusion and exclusion criteria. In the initial phase, 442 records were obtained from the Dimensions AI using the keywords "problem-based learning" and "mathematics education." This is followed by the screening phase related to publication type, where 381 articles were recorded and 31 non-research articles were eliminated, resulting in 350 articles being assessed for eligibility. Accordingly, 76 articles were excluded for not aligning with this study's inclusion criteria, specifically because they were either irrelevant to education or not available as open-access (OA) content. Finally, 274 papers were included in the final phase of this selection process and were relevant in the scope of research in this current study.

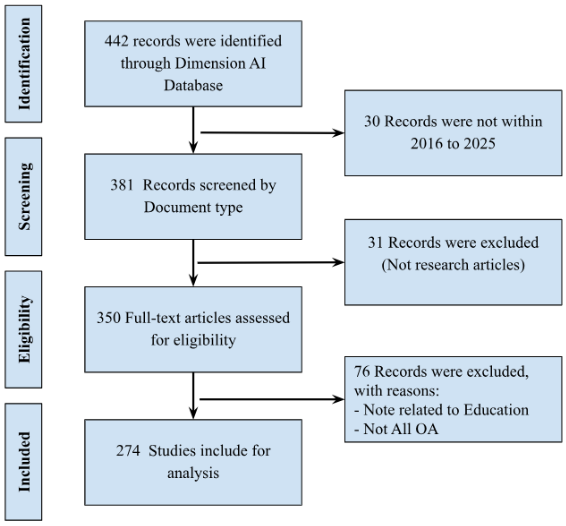

Figure 1. PRISMA Flowchart

C. Data Analysis Techniques

The data analysis was conducted using VOSviewer software to determine prominent contributors by published articles, journals, authors, institutions, and countries and to identify key research themes within the field of PBL in mathematics education. This data visualisation method is extensively applied to the visualisation of bibliometric networks and publication relationships. The performance analysis was initially conducted to identify the most high-impact publications, journals, authors, institutions, and countries with the analysis of the output of publications and citation patterns, focusing on the identification of the key contributors in the field. This is followed by the bibliographic coupling analysis to identify key research themes and clusters through the exploration of the relationship among documents based on shared references. Finally, the analysis of keyword co-occurrence was conducted to identify dominant research themes and clusters by groups of keywords that appear together in the same contexts. Thus, in such analyses, the present study offers an in-depth insight into the trends in collaboration and the

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themes of investigation within the field of PBL research in mathematics education.

IV. RESULT ANALYSIS

A. Publication Trends of PBL Research in Mathematics Education

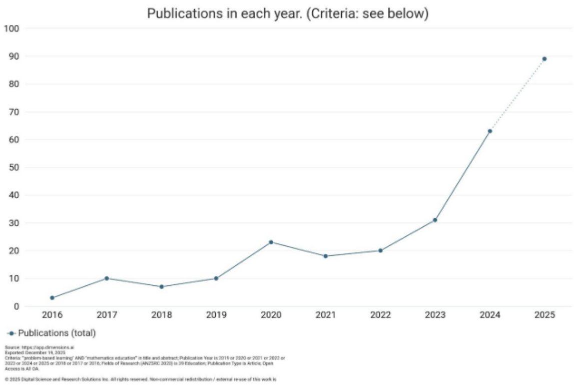

Figure 2. Quantity of Publications Between 2016 and 2025

The analytical overview of Dimensions AI provided in Figure 2 depicts the annual publication trends on PBL in mathematics education between 2016 and 2025. With a total number of 274 publications, this analytical result indicates a significant increase in research over a decade, particularly starting from 2023 onwards. The trend demonstrates a long-term scholarly interest in the field of PBL in mathematics education as one of the effective practices. Moreover, the average citation score of 3.04 in the dataset indicates the overall citation performance of the published studies in all the publications, which is suggestive of a gradual adoption of the literature by the academic community. Although the number of citations remained fluctuating over time, the data shows that there was a different level of visibility and impact of research in the field. Overall, the results indicate that the research activity in PBL within the domain of mathematics education is on the rise as the number of publications grows over the last ten years.

B. Performance Analysis

1) Document

Table 2
Performance Analysis by Document

Rank	Author	Title	Citation
1	Baker and Galanti [59]	Integrating STEM in elementary classrooms using model-eliciting activities: responsive professional development for mathematics coaches and teachers	83
2	Fery at al. [60]	Improving primary students mathematical literacy through problem-based learning and direct instruction	77
3	Yuliati and Lestari [61]	Higher-order thinking skills (hots) analysis of students in solving hots question in higher education.	76
4	Zakaria et al. [62]	A systematic review of problem-based learning in education	51
5	Norqvist et al. [63]	Investigating algorithmic and creative reasoning strategies by eye tracking	45
6	Zetriuslita et al. [64]	Mathematical Critical Thinking and Curiosity Attitude in Problem-Based Learning and Cognitive Conflict Strategy: A Study in Number Theory course	30
7	Rosa and Pujiati [65]	Pengaruh Model Pembelajaran Berbasis Masalah Terhadap Kemampuan Berpikir Kritis dan Kemampuan Berpikir Kreatif	25
8	Benedicto and Andrade [66]	Problem-Based Learning Strategies and Critical Thinking Skills Among Pre-Service Teachers	22
9	Awaludin et al. [67]	Integral Calculus Learning Using Problem-Based Learning Model Assisted by Hypermedia-Based E-Book	19
10	Amalia and Isnani [68]	Representasi Matematis dalam Pembelajaran dengan Model Problem-Based Learning Berbasis Etnomatematika Ditinjau dari Tipe Kepribadian	16

The analysis of the document-level performance determined the most effective studies that contribute to researching the concept of PBL in mathematics education, as shown in Table 2. The most highly cited work, with 83 citations, was [59], who provided a theoretical basis of model-eliciting activities and professional development, which places PBL in the framework of STEM-oriented mathematics teaching. [60]-[61], with citations of 77 and 76, respectively, built on this impact by showing, through empirical evidence, that PBL was effective in enhancing mathematical literacy and higher-order thinking abilities. [62] presented a systematic review that summarises the existing evidence on the positive effects of PBL in various educational settings at the synthesis level, thus supporting its theoretical appropriateness, and earned 51 citations. Accounting for 45 citations, [63] further investigated algorithmic and creative reasoning in problem-solving through students' eye tracking. With a moderate number of 30, 25, and 20 citations, respectively, [64]-[66] further focused on the results of critical and creative thinking within the context of classroom-based and higher-education research. More recent works, such as [67]-

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[68], respectively, were devoted to the mathematical research of PBL-based instructional-design innovations, including PBL-based e-books and PBL-based ethnomathematics, thus exemplifying the pedagogical diversity of PBL studies.

2) Source

Table 3
Performance Analysis by Source

Rank	Source	Document	Citation	Total Link Strength
1	Berkala Ilmiah Pendidikan Biologi (BioEdu)	9	42	1
2	IT-Edu Journal Information Technology and Education	9	1	0
3	Jurnal Elemen	8	53	0
4	Jurnal Pendidikan Teknik Elektro	8	2	0
5	Al-Jabar Jurnal Pendidikan Matematika	5	10	0
6	Jurnal Pendidikan Mipa	4	4	1
7	Unesa Journal of Chemical Education	4	0	0
8	Aksioma Jurnal Program Studi Pendidikan Matematika	3	4	0
9	Alphamath Journal of Mathematics Education	3	3	0
10	JME (Journal of Mathematics Education)	3	3	0

As shown in Table 3, a summary of performance analysis by sources was presented. In mathematics education, this analysis revealed that regional and discipline-focused journals were the primary sources of research on PBL. For instance, Berkala Ilmiah Pendidikan Biologi (BioEdu) and IT-Edu Journal Information Technology and Education stood out as the pivotal sources, each contributing the highest number of nine documents, which indicated their openness towards PBL-related studies. However, their impact in terms of citations was considerably varied, with 42 and 1 citations, respectively. The following journal, which also stood out as the leading journal, was Jurnal Elemen, earning the highest number of 53 citations while contributing 8 publications. This journal demonstrated higher visibility and scholarly influence across sources, specifically compared to Jurnal Pendidikan Teknik Elektro, which has a similar publication of 8 documents. In contrast, other journals with a minimal publication of 4 documents (e.g., Jurnal Pendidikan Mipa) and low citation counts reflected emerging citation trajectories. Ultimately, there was a limited cross-journal citation integration for low total link strength across most sources, which implied a circulation of PBL research in mathematics within specific journal communities. Therefore, it is necessary to enhance the visibility and impact of PBL research through an internationally indexed journal for wider dissemination.

3) Author

Table 4
Performance Analysis by Author

Rank	Author	Document	Citation	Total Link Strength
1	Ekohariadi, E.	4	1	0
2	Juandi, D.	4	26	0
3	Dahlan, J. A.	3	2	0
4	Harimurti, R.	3	1	0
5	Fery, M. F.	2	79	1
6	Susanta, A.	2	5	1
7	Susanto, E.	2	3	1
8	Zakaria, M. I.	2	15	1
9	Abadi, A. M.	2	3	0
10	Abubakar, S.	2	0	0

As shown in Table 4, a summary of performance analysis by the authors was presented. In the context of PBL mathematics literature, this summary demonstrated a distinction between productivity and authors' impact. Based on the summary, both Ekohariadi, E. and Juandi, D. stood out as leading authors, each contributing four publications. However, their impact on citation counts considerably varied, with 1 and 26 citations, respectively. The following two authors, Dahlan, J. A., and Harimurti, R., were moderate contributors to PBL research in mathematics education, each contributing 3 papers

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and, respectively, being cited 2 and 1. Fery, M. F., was found to have a remarkable impact, being cited 79 times, even though he only contributed two publications. This indicated that studies on PBL in mathematics education have high-impact contributions. Similarly, the academic work of Zakaria, M. I., reflected a substantial impact relative to the contributions of systematic reviews, with it having 15 citations in two publications. On the other hand, Susanta, A., Susanto, E., Abadi, A. M., and Abubakar, S. added two publications to the list of moderate citations of 5, 3, and 3, respectively. It is important to note that the overall interrelations between these respected authors were low in nature, suggesting that there were few networks of collaboration. Therefore, it is necessary to strengthen international and inter-institutional co-authorship to enhance theoretical convergence and increase citation reach within global PBL mathematics research.

4) Organisation

Table 5
Performance Analysis by Organisation

Rank	Organisation	Document	Citations	Total Link Strength
1	State University of Surabaya	22	45	1
2	Indonesia University of Education	9	110	2
3	State University of Semarang	6	13	1
4	State University of Jakarta	5	103	0
5	National University of Malaysia	3	53	1
6	Islamic University of Riau	3	4	0
7	State University of Medan	3	0	0
8	University of Mataram	2	5	1
9	Indraprasta PGRI University	2	8	0
10	Lambung Mangkurat University	2	1	0

As shown in Table 5, a summary of the performance analysis by organisations was presented. Research into the advancement of PBL in mathematics education indicated that public institutions play a crucial role. For instance, the State University of Surabaya led the way, which published 22 papers and being cited 45 times. This strong showing is in line with the emphasis it places on teaching innovations. With a smaller publication output of nine papers, the Indonesian University of Education has had a more substantial research influence, indicated by 110 citations. In terms of the number of citations, the third-place university, the State University of Semarang, with 13 citations, was closely followed by the State University of Jakarta with 103 citations and the 5th-place National University of Malaysia with 53 citations. The results indicated that research quality was more closely associated with citation influence disparities than with the output quality. Other universities in Indonesia, which include the Islamic University of Riau, State University of Medan, University of Mataram, and the Islamic University of Riau, Indraprasta PGRI University, and Lambung Mangkurat University, contributed moderately with a smaller volume of publications and a lower citation count. Moreover, there appeared to be a weak overall total link strength within educational institutions. This suggested little collaboration among them, which could lead to wider university research collaborations to strengthen PBL research methods and increase visibility of this research in the international mathematics education community.

5) Country

Table 6
Performance Analysis by Country

Rank	Country	Document	Citation	Total Link Strength
1	Indonesia	95	406	2
2	Malaysia	5	55	1
3	United States	2	84	0
4	Uganda	2	1	0
5	Portugal	1	8	0
6	United Kingdom	1	7	0
7	Taiwan	1	2	1
8	Turkey	1	2	0
9	Bosnia and Herzegovina	1	0	0
10	China	1	0	0

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As shown in Table 6, a summary of performance analysis by countries was presented. Indonesia was the most dominant contributor to the research landscape with 95 documents and 406 citations. It was followed by Malaysia, with a notable impact of 55 citations, even though this country contributed a small number of 5 publications, showing a significant contribution to the body of knowledge. Similarly, the United States stood out with a high citation count of 84 despite its minimal output in 2 documents, which suggested a strong influence of research on PBL from Western contexts. In contrast, several other countries demonstrated the least contribution in both publications and citations, showing their limited engagement in PBL studies, such as Uganda, the United Kingdom, Taiwan, Turkey, and Bosnia and Herzegovina. Ultimately, a low total link strength across countries was found. This indicated that their collaboration is weak, which highlighted a need to strengthen the global knowledge on PBL in mathematics education through research partnerships.

C. Bibliographic Coupling Analysis

1) Bibliographic Coupling by Document

Tabble 7
Bibliographic Coupling by Document

Rank	Author	Title	Citation	Total Link Strength
1	Baker and Galanti [59]	Integrating STEM in elementary classrooms using model-eliciting activities: responsive professional development for mathematics coaches and teachers	83	1
2	Fery at al. [60]	Improving primary students mathematical literacy through problem-based learning and direct instruction	77	2
3	Yuliati and Lestari [61]	Higher-order thinking skills (hots) analysis of students in solving hots question in higher education.	76	15
4	Zakaria et al. [62]	A systematic review of problem-based learning in education	51	4
5	Norqvist et al. [63]	Investigating algorithmic and creative reasoning strategies by eye tracking	45	0
6	Zetriuslita et al. [64]	Mathematical Critical Thinking and Curiosity Attitude in Problem-Based Learning and Cognitive Conflict Strategy: A Study in Number Theory course	30	0
7	Rosa and Pujiati [65]	Pengaruh Model Pembelajaran Berbasis Masalah Terhadap Kemampuan Berpikir Kritis dan Kemampuan Berpikir Kreatif	25	0
8	Benedicto and Andrade [66]	Problem-Based Learning Strategies and Critical Thinking Skills Among Pre-Service Teachers	22	0
9	Awaludin et al. [67]	Integral Calculus Learning Using Problem-Based Learning Model Assisted by Hypermedia-Based E-Book	19	7
10	Amalia and Isnani [68]	Representasi Matematis dalam Pembelajaran dengan Model Problem-Based Learning Berbasis Etnomatematika Ditinjau dari Tipe Kepribadian	16	1

The analysis of bibliographic coupling revealed the ten most frequently used sources, which can be seen in Table 7 as the landmark sources in the study of PBL in mathematics education. The review found that these studies were influenced by a strong degree of interdependence, as demonstrated by the fact that they all share certain references, and thus, it can be inferred that these studies were oriented towards the theory of solving problems, higher-order thinking skills (HOTS), and learner-centred pedagogy. The article by [61] appeared to be the most salient, which featured HOTS and attained the greatest total linking strength of 15 and 76 citations. Further, [67] were able to achieve the total link strength of 7 and 19 citations; their research included PBL and hypermedia e-books, which provided a possibility to obtain empirical data on contextual innovations. Simultaneously, [68] examined the integration of PBL and ethnomathematics, thus adding to these results. The systematic review done by [62] with a total link strength of 4 and 51 citations was critical in linking the empirical study in the different contexts, thereby acting as conceptual bridges. Moreover, the citation counts of 83 and 77, respectively, for the research by [59]-[60] were used to anchor the network by connecting it to the aspects of STEM integration and mathematical literacy with primary-school learners, which all have total link strengths of 1 and 2. Together, these works depict an inner circle of scholarship that implies the ability to construct

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knowledge cumulatively, and that there exists a common theoretical oversight on the basis of the study of mathematics PBL.

2) Bibliographic Coupling Analysis by Cluster

As illustrated in Figure 3, the bibliographic analysis provided valuable insights with three distinct, yet interrelated thematic clusters in the context of PBL research in mathematics education. In each of these clusters, as presented in Table 8, emphasised pedagogical scaffolding and learning supports, a conceptual bridge between theory and practice, as well as cognitive investigation of problem-solving, innovation, and contextual adaptation of PBL in mathematics. Together, these clusters demonstrated a layered research landscape of PBL in mathematics education that encompasses pedagogical theory, cognitive processes, and instructional innovation.

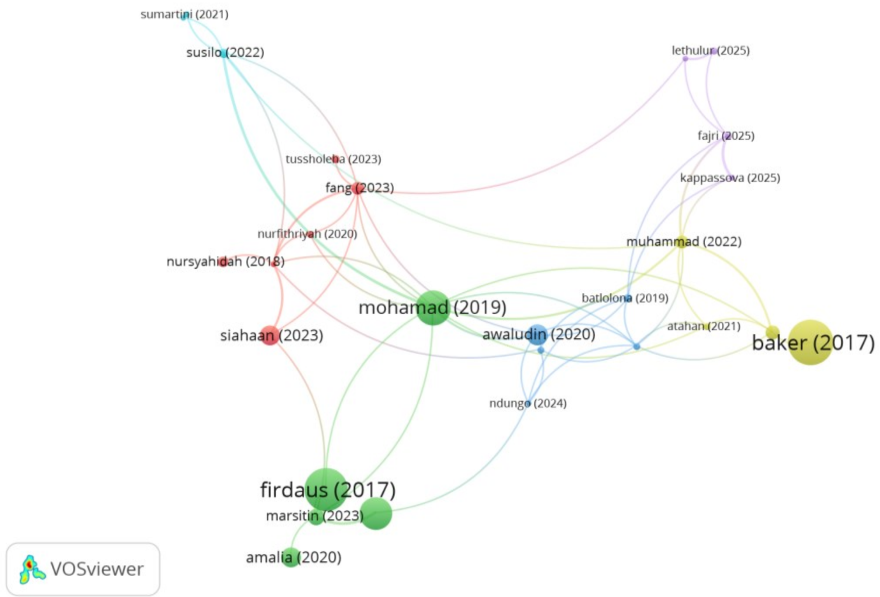

Figure 3. Bibliographic Coupling Analysis (VOSviewer Visualisation)

Table 8
Bibliographic Coupling Analysis by Cluster

Cluster No and Colour	Cluster Label	No of Article	Representative Publication
Cluster 1 (Red)	The Development of Critical Thinking and Problem-Solving Skills	6	Fang et al. [5]; Nurfithriyah et al. [75]; Nursyahidah and Albab [71]; Permatasari et al. [70]; Siahaan et al. [69]; Tussholeha et al. [74]
Cluster 2 (Green)	Mathematical Literacy, Reasoning, and Conceptual Competence	5	Amalia et al. [51]; Fery et al. [60]; Marsitin and Sesanti [44]; Zakaria et al. [62]; Norqvist et al. [63]
Cluster 3 (Blue)	Technological Integration and Innovative Instructions	5	Agusdianita et al. [76]; Awaludin et al. [67]; Kempa et al. [43]; Ndungo et al. [72]; Pinos et al. [73]

a) Cluster 1: The Development of Critical Thinking and Problem-Solving Skills

In Cluster 1, there are six articles, as presented in Table 8, emphasizing PBL as a teaching method to promote critical thinking in mathematics education. In addition, these studies addressed challenges and reflected classroom practices of PBL. For instance, [69] provided a conceptual understanding of PBL research trends by highlighting PBL and STEM-oriented approaches as dominant thematic strands through a collective review of research on pre-service mathematics teachers' critical thinking. Furthermore, [5] emphasized the central role of mathematics teachers as facilitators in supporting students' critical thinking and their development in problem-solving; simultaneously, they underscored systematic challenges in PBL implementation. Most recently, [70] synthetically demonstrated that PBL was a common instructional strategy employed to enhance students' critical thinking across educational levels, including primary schools. Moreover, [75] provided empirical classroom-based research with various learning models that allowed teachers to help students improve their mathematical critical thinking skills, one of which was PBL. [71] further underscored the

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need for PBL interventions by revealing persistent weaknesses in problem-solving ability among low-achieving students, especially in inference and advanced mathematics reasoning. Finally, [74] made a confirmation on the practical effectiveness of PBL by developing PBL learning worksheets that illustrate how PBL-based instructional materials operationalise the development of students' critical thinking in mathematics classrooms.

b) Cluster 2: Mathematical Literacy, Reasoning, and Conceptual Competence

In Cluster 2, five research studies were identified, as presented in Table 7, examining the degree to which PBL improves the mathematical literacy, representation, and reasoning of the students in various instructional designs and across educational levels. In relation to the mathematical representation, [51] indicated that PBL, with the assistance of GeoGebra and Realistic Mathematics Education (RME), enhanced students' representational competence in mathematics. However, the intensity of such impact may depend on students' personal learning styles. According to [60], PBL generated considerably higher increases in mathematical literacy in comparison with direct instruction, particularly in solving real-life problems. The evidence concerning the effectiveness of PBL was further supported by development-oriented evidence, as [44] indicated; PBL-based e-modules enhanced mathematical reasoning in students and were an option that can be applied instead of conventional instruction. Moreover, through a systematic review, [62] made a confirmation that PBL produces beneficial learning results in various fields across educational levels. In addition to these results, [63] indicated that the more problem-oriented, creative thinking strategies are more effective in developing deeper mathematical thinking as compared to algorithmic ones.

c) Cluster 3: Technological Integration and Innovative Instructions

In Cluster 3, five research studies were identified, as presented in Table 4.7, representing a consistent body of PBL research that can be applied to address the ongoing challenges in mathematics teaching research across a wide range of contexts and educational levels. At the primary school level, [76] demonstrated how the use of instructional materials by integrating PBL with a differentiated learning approach using the ADDIE model addresses abstract mathematical concepts to enhance students' learning experiences and outcomes. Moving to a technology-based environment, [67] stated a superiority in learning in the context of integral calculus on the hypermedia-based PBL model, which suggests that the structured context of problems with the use of digital tools promotes conceptual learning. In addition, [43] provided comparative evidence and found that PBL is better than realistic mathematics education in enhancing students' academic achievements, especially in the ability to maintain engagement through online media. Systematically, [72] emphasised geometrical weaknesses in national assessments and believed that strategies based on PBL and active and technology-supported teaching are obligatory to increase the level of problem-solving competency and quality of responses. Despite the difficulties with its implementation, [73] concluded that PBL can and should always stimulate the further regulation of mathematical thinking of the higher order and the practical competence to solve problems, which only proves its usefulness in pedagogy in the various fields of mathematics.

3) Co-Occurrence Analysis

Table 9
The 15 most frequent keywords in co-occurrence analysis

Rank	Keyword	Occurrences	Relevance
1	Problem	273	0.53
2	Study	232	0.42
3	Mathematics Education	213	0.35
4	Student	196	2.09
5	Research	158	2.41
6	Mathematics	158	0.17
7	Model	151	2.05
8	PBL	145	1.48
9	Approach	137	2.40
10	Learning	131	2.41
11	Skill	123	1.97
12	Ability	117	1.95
13	Analysis	99	2.43
14	Data	88	2.10
15	Development	81	2.44

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The co-occurrence analysis of keywords provided insight into the conceptual focus and research orientation of studies concerning PBL in the mathematics learning process. As presented in Table 9, the keywords, such as problem, mathematics education, student, PBL, learning, and skill, were used at very high frequency, which gives the impression that most of the literature discussed the student engagement in mathematical problem solving and how a student can develop their domain-specific skills. The predominant utilise of other keywords, such as approach, model, ability, and development, suggested that PBL has become a consistent mode of conceptualisation aimed enhance the cognitive and problem-solving abilities of the students. Moreover, the predominance of such terms as data, research and analysis used in the methodological framework is an indication of the growing tendency towards interest in empirical validation and evidence-based pedagogy.

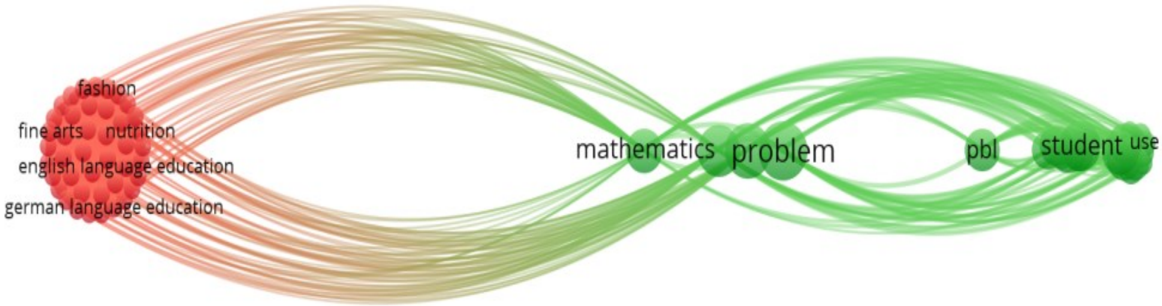

Figure 4. Co-Occurrence Analysis (VOSviewer Visualisation)

Table 10
Co-Occurrence Analysis by Keyword

Cluster No and Colour	Cluster Label	Number of Keyword	Representative Keyword
Cluster 1 (Red)	Cross-Disciplinary Applications of PBL	15	“English language education”, “English literature”, “fine arts education”, “geography education”, “fine arts”, “German literature”, “portal”, “German language education”, “graphic design”, “fashion”, “information systems”, “teacher professional education”, “nutrition”, “history education”, “music art”
Cluster 2 (Green)	PBL in Mathematics Education and Cognitive Skill Development	15	“mathematics education”, “pbl”, “problem”, “approach”, “ability”, “learning”, “skill”, “implementation”, “critical thinking”, “development”, “analysis”, “effectiveness”, “mathematics”, “research”, “outcome”

Together, the keyword distribution suggested that studies in mathematics on PBL focus on the effectiveness of the instruction, student achievement, and analytic quality, thus highlighting the level of maturity of a field that ensures the synthesis of discoveries in pedagogical application and systematic, empirical research. Furthermore, in the cluster-based co-occurrence analysis, two instances of thematic groupings were identified that define the interdisciplinary breadth of the literature and the disciplinary focus of the literature, as presented in Table 10. Taking into consideration thematic coherence and representative keywords, a person can give suitable labels to increase interpret ability and transparency of methods.

Cluster 1 included keywords that relate to education and a more general background that encompasses language education, fine arts, history, geography, and teacher professional education. This collection pointed to the fact that PBL is not limited to mathematics but is extensively used in various areas of the subject, which suggests the flexibility of the method as a pedagogical tool. On the contrary, Cluster 2 was directly math-oriented, with the keywords mathematics education, PBL, problem, critical thinking, learning, skill, effectiveness, and outcome predominantly taking the centre stage. The group was the main line of research on how PBL affects mathematical knowledge, cognitive, and learning results. The distinctive distinction of clusters indicated a high degree of disciplinary unification of the mathematics PBL study, and at the same time, it has to connect to the wider educational practice.

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Together, the described clusters complied with the intellectual architecture identified by the co-occurrence network, and they were compatible with the existing bibliometric reporting norms. Therefore, cluster labels were also well-defined, which was an added strength to the correspondence between the analysis of keywords and the substantive meanings of PBL research trends in the mathematics education field.

IV. DISCUSSION

This bibliometric analysis provides in-depth data regarding the current growing academic interest in PBL in mathematics education. The analysis of publication patterns, impact of citation, patterns of source distribution, collaborative organisation, and thematic clusters to explain the developmental trend and present dissemination of PBL-related studies clarifies the research topic. Instead of directly evaluating the efficacy of the instruction, the discussion interprets findings of this bibliometric analysis to elaborate on the maturity, influence, and future direction of the research on PBL in mathematics education.

A. Research Trends of PBL Research in Mathematics Education

The publication trend analysis from 2016 to 2025 reveals a continual upward trend in PBL research within mathematics education. Over the years, between 2016 and 2019, there was a relatively low and fluctuating number of annual publications. This initial phase reflects an exploratory stage in the development of PBL research, in which scholars attempted to empirically justify PBL implementation into mathematics classrooms. Subsequently, there was a significant growth in the number of publications during 2020, with a slight downward trend in 2021, but it was followed by steady growth throughout 2023. Although there was a slight decrease within the whole year between 2021 and 2022, it is comparatively twofold higher than it was observed in the previous years. From 2023 onwards, a major growth pace is incurred, which indicates a rapid expansion of PBL research in mathematics education has taken place. Moreover, the dataset shows a moderate level of academic visibility with an average citation mean of 3.04 citations per article, along with an increase in the number of publications. The average mean of this citation value indicates an increasing influence that is proportionate to an increasing domain of study. However, while a growing number of publications is quantitatively observed, the broader scholarly influence and theoretical consolidation of PBL research in mathematics education remain at the stage of development.

B. Contribution of Journal Sources, Authors, Institutions, and Countries Contribute to PBL Practices in Mathematics Education

The performance analysis on the contribution of journal sources, authors, organisations, and countries highlighted a structural concentration, yet it is fragmented within the research framework. The number of publications at the journal-source level is distributed inconsistently across multiple education-oriented journals. While some journals contribute a significant number of publications, such as Berkala Ilmiah Pendidikan Biologi (BioEdu) and Jurnal Elemen, others contribute relatively low. In addition, the citation impact varies among different journal sources. Although their publication productivity exhibits relatively strong influence, their citation impact remains low, for instance, in IT-Edu Journal Information Technology and Education and Jurnal Pendidikan Teknik Elektro. Despite the difference in the publication and citation performance, the value of total link strength remains consistently low across multiple journal sources, which indicates that the inter-journal and citation connectivity is limited. This occurrence suggests that PBL research in mathematics education has not yet been centralised within a strongly interconnected journal network, although it is actively distributed across various journal outlets. Therefore, rather than being structurally integrated, the scholarly journal circulation appears to be disconnected, which reinforces the fragmentation of the publication framework.

As follows, the analysis at the author level shows that the productivity is distributed across multiple contributors, where the most prolific authors produce at least 2 to 4 publications. Relatively, this low number of publications indicates that there is an absence of a single dominant contributor within the PBL research community. In addition, the significant variation in citation impact among these authors was recorded. While some contributors demonstrate comparatively higher citation counts, such as Juandi, D.; Fery, M. F.; and Zakaria, M. I., the majority of authors exhibit relatively low citation influence that indicates inconsistency in academic visibility. Notwithstanding, the value of total link strength is relatively and consistently low, representing the minimal collaborative connectivity among these respective authors. This occurrence suggests that the PBL research activity, rather than being embedded in cohesive international networks, is mostly performed within small and institutionally connected groups. Therefore, this finding demonstrates that the authorship framework of PBL research in mathematics education is driven by limited structural integration, low citation impact, and moderate productivity.

Accordingly, the analysis at the organisational level highlights the contribution of publication output across a number of universities, where the State University of Surabaya was recorded with the most significant number of publications compared to

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others. This indicates that there is a strong institutional hub, which drives the PBL research productivity in mathematics education. Nevertheless, the citation impact across multiple institutions is varied; for instance, the Indonesia University of Education and the State University of Jakarta have high citation impact despite publishing a moderate number of documents. Moreover, the total strength values of the linkage between different organisations are consistently low. The indicator of this low collaboration indicates that the effort of institutional research is predominantly localised rather than highly embedded within interconnected national or global networks. Taken together, although some universities play an important role as a productive centre of scholarship that reinforces a structurally concentrated framework, the academic framework is merely connected, and the collaboration across institutions and cross-organisational integration remains limited.

Furthermore, the analysis result at the country level revealed that the research on PBL in mathematics education is highly associated with a small number of nations. Indonesia stood out as the leading contributor, with the highest publications and citations. The presence of this dominance is indicative of the national commitment on a large scale and institutional interest in investigating PBL in mathematics education. Simultaneously, its citation impact showed a significant scholarly visibility. However, other countries, such as Malaysia and the United States, showed a comparatively high citation impact despite contributing minimal publications. This indicates that there is a disparity between the productivity and the impact of research across national settings. Besides, the values of the total link strength are relatively low, which indicates that there is a weak link in collaboration between countries. The low connectivity across countries, rather than being carried out as part of expanded international collaboration, implies that the research activities are mostly performed among nationally based scholastic networks. This finding indicates that the PBL research environment is marked by high nationalisation and low globalisation; therefore, it is necessary to further investigate for more comprehensive collaboration at the international setting to enhance knowledge sharing and scholarly interest in the field of study.

C. The Central Themes of PBL Research in Mathematics Education

The PBL research in mathematics education demonstrated structured intellectual configuration through thematic synthesis, which derived from both co-occurrence and bibliographic analyses. The co-occurrence analysis demonstrated a two-thematic framework of the research of PBL based on keywords. The first cluster (red) reflected on cross-disciplinary uses of PBL in diverse subject areas, such as language education, arts, and information systems. The second cluster (green), however, centred on PBL implementation in mathematics education that emphasized critical thinking, the development of skill, ability, and learning, and research on effectiveness and outcomes. This finding suggested that PBL, although shown to be a general teaching approach used in various subjects, is still mainly focused on classroom-based application to improve cognitive competencies in mathematics education.

Furthermore, the analysis of bibliographic coupling provided a more comprehensive thematic framework, which was categorized into three interconnected clusters. The first dominant cluster (red), which is the development of critical thinking and problem-solving skills, emphasized structured instructional strategies designed to enhance higher-order thinking and analytical skills within mathematics classrooms. This finding is consistent with a systematic review of [70], who situates PBL as an important teaching method that has been implemented on different educational levels and shown a beneficial impact on the development of the critical thinking of students. In addition to critical thinking, [5] also supports this finding by further indicating that PBL promotes students' problem-solving and collaborative teamwork through active involvement and the facilitation of teachers. Moreover, the finding on this cluster is also supported by current meta-analysis studies that demonstrate a significant effect of PBL in improving students' thinking skills in mathematics [77]-[78].

As follows, the second cluster (green) was recorded, emphasising mathematical literacy, reasoning, and conceptual competence. In contrast to the first cluster, which focuses on PBL intervention orientation, this cluster reflects an in-depth engagement with conceptual comprehension and cognitive architecture that underpins mathematical learning. As highlighted in [60]'s work, PBL has a potential role in improving students' mathematical literacy that enables them to understand mathematical concepts and solve problems. In addition, [44] also supported this finding, where PBL and mathematical literacy were integrated as an approach based on producing an e-module to enhance students' mathematical reasoning. Moreover, in relation to students' conceptual competence, previous literature support this finding, indicating the potential of PBL in facilitating long-term knowledge construction and meaningful learning through small group activities that encourage students to activate their prior knowledge and give them an opportunity to elaborate on that knowledge [80].

Moreover, the third cluster (blue), technology integration and innovative instructions, highlights supportive mathematics learning through the integration of digital learning tools, hypermedia resources, and online learning media. This further

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emphasises the development of learning materials and delivery modalities, which align with the current educational needs and reflect the digitalisation evolution of instruction in mathematics. This has been highlighted in [43]'s work, where students were facilitated with online-based media in the PBL framework that attracted their attention in learning and improved their academic performance. Another study, such as [67], also supports this finding demonstrating that PBL effectively improve students' learning outcomes in integral calculus with the assistance of a hypermedia-based e-book. In addition, this finding is supported by a current bibliometric study showing that the integration between PBL and educational technology help students enhance their critical thinking and problem-solving abilities [81].

Taken together, the central core of these findings emphasises intellectual orientation – the development of higher-order thinking in mathematics through structured, context-driven problem-solving approaches within PBL practices. The concentration of these themes remains predominantly classroom-focused and cognitively driven, even though the PBL research demonstrates significant pedagogical growth and emerging technological diversification. In mathematics education, while PBL research is developing internal coherence, this further suggests theoretical integration and broader systemic exploration that strengthen its conceptual maturity.

D. Emerging Research Themes and Future Directions

In recent years, despite a significant increase in the number of publications, which indicates an increase in scholarly interest in PBL in mathematics, this study's findings indicate regional clusters and comparatively low levels of cross-national collaboration. Indonesia substantially dominates both publication output and citation impact, followed by Malaysia and the United States, with a relatively low total link strength, which suggests that a large portion of the publications in this research domain has been carried out individually without the participation of collaborators from other countries. As supported by current bibliometric studies, including [81] and [82], this regional concentration reflects a fragmentation of the research landscape that limits knowledge sharing and the development of globally integrated research networks. In addition, the bibliometric review provided by [83] also highlights the importance of further collaboration at the cross-national level to improve the quality of research and increase the relevance of PBL to various learning settings. As such, future studies must focus on the adoption of international collaboration and cross-cultural research in the study of mathematics education by giving priority to international partnering and comparisons.

As a thematic aspect, the existing literature has a strong focus on the classroom-based interventions that are aimed at improving students' cognitive abilities [51], [74]-[76]. Such studies, though providing substantive information on the efficacy of instruction, indicate that the highly focused consideration that has been given to the competence development shows that broader theoretical, longitudinal impact, policy-level integration, and cross-national comparative studies have generally been inadequately addressed. This is in line with the current bibliometric and meta-analysis literature, including [82] and [85], that suggests PBL research conducted in the field of mathematics education has been largely focused on the short-term learning outcomes, with less consideration of long-term growth and cross-contextual comparisons. Hence, as highlighted by [81]-[82], [84], the attention of future research must be extended not only to the classroom setting but also to longitudinal studies, cross-national comparisons with other countries, and integration of curriculum-level PBL with teacher professional development and policy consideration to help establish sustainable implementation of PBL in mathematics education.

The increased emphasis on integrating technology to support students' learning indicates a key emerging direction of PBL research in mathematics education. Previous studies highlight a growing use of digital learning resources, such as online-based media, hypermedia-based e-books, GeoGebra, and a mathematical literacy e-module as PBL's assistive technology to improve students' academic performance, learning outcomes, mathematical representations, and mathematical reasoning [43], [44], [51], [67]. In addition, current bibliometric studies further support this emerging trend by advocating for the digital transformation and the advancement of technology-based practices, which involve the integration of e-learning, computational modelling, and computer-aided instruction and active learning and blended learning approaches [81]-[82]. Moreover, [81] highlights that future research should further focus on the exploration of advanced applications, including the integration of artificial intelligence (AI) for adaptive problem design; learning analytics for tracking students' problem-solving progress and real-time feedback; and transdisciplinary PBL approaches to address real-world challenges. Such developments are critical towards making PBL relevant and sustainable in a digitally fast-changing world of mathematics education.

V. CONCLUSION

This study provides a comprehensive bibliometric review of PBL in mathematics education based on the publications indexed in the Dimensions AI database. The findings indicate that the volume of publications has been steadily increasing in a positive trend over

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time, which is indicative of the increasing scholarly interest in the implementation of PBL as a pedagogical approach in mathematics instruction. However, the limited cross-national collaboration and weak integration across scholarly networks were observed, as reflected by the regionally concentrated research landscape and its structural fragmentation. The thematic analysis highlights three core interrelated clusters that mainly focus on the development of students' cognitive competence and the integration of technology-based practices in PBL, including critical thinking and problem-solving skills, the improvement of mathematical literacy, reasoning, and conceptual competence, and the growing integration of technology and innovative instruction. While this PBL research demonstrates strong pedagogical development, these findings indicate that the field remains predominantly classroom-focused and requires broader theoretical and global network expansion.

The contribution of the study centres on the mapping of intellectual structure and the establishment of the main gaps and future research directions of the development of PBL research in the field of mathematics education. It underlines that there is a necessity for strong international collaboration and comprehensive integration of the theories and innovation in the form of technology-based practices. Nevertheless, this bibliometric review is limited by using a single database, the Dimensions AI, and the inclusion criteria of open-access (OA) articles. With this key limitation, this study may introduce potential bias in the bibliometric analysis with the exclusion of high-impact studies on PBL in mathematics education that have been published in subscription-based journals. As a result, citation counts and bibliometric measures, such as total link strength, might not be sufficient to represent the global research landscape. Therefore, it is recommended that future research conduct an extended analysis incorporating various databases, which are to include open-access and subscription-based journals, as well as apply a more extensive set of methods to offer a more comprehensive and balanced analysis and to construct an insight into the research domain of PBL in mathematics education.

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