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IMPLEMENTATION AND RESEARCH TRENDS OF PROBLEM-BASED LEARNING IN MATHEMATICS EDUCATION AT SCHOOL: A SYSTEMATIC LITERATURE REVIEW

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Abstract

Problem-Based Learning (PBL) is widely used in mathematics education to encourage active student participation and the development of higher-order thinking skills. Therefore, this study aims to examine the implementation and research trends of Problem-Based Learning (PBL) in school mathematics learning through a Systematic Literature Review (SLR). The review followed the PRISMA framework and searched articles in the Scopus database published during 2020-2025. From 200 identified records, eight articles met the inclusion criteria and were included in the final analysis. The findings reveal that PBL is generally implemented through problem orientation, group organization, investigation, presentation, and reflection or evaluation, although variations exist in learning context and instructional integration. In addition, PBL research is still dominated by senior high school contexts, quasi-experimental methods, and higher-order cognitive outcomes, particularly problem-solving and critical thinking skills. These findings indicate that while PBL has been implemented consistently in mathematics education, opportunities remain for broader research across educational levels, learning outcomes, and instructional integrations.

Keywords: Mathematics Education, PRISMA, Problem-Based Learning, Systematic Literature Review

INTRODUCTION

Mathematics learning plays an important role in developing students' logical, analytical, systematic, and problem-solving abilities (Cresswell & Speelman, 2020; Kafillah et al., 2025). Through mathematics education, students are expected to understand concepts, recognize relationships among concepts, and apply mathematical knowledge in various real-life situations. However, in classroom practice, mathematics is still often perceived as an abstract and difficult subject by many students (Susac et al., 2014; Yumiati et al., 2025). This condition is closely related to instructional practices that are still dominated by lectures and routine exercises, resulting in limited student participation during the learning process (Agatep & Villalobos, 2020; Udin & Arfanaldy, 2025).

Such conditions affect students' conceptual understanding and higher-order thinking skills, including problem-solving, reasoning, and mathematical communication. Many students tend to memorize procedures without fully understanding the underlying mathematical concepts (Dalia et al., 2025; Hartoyo, 2018; Hendriana et al., 2023). As a result, students often encounter difficulties when dealing with contextual or non-routine mathematical problems. These challenges suggest that more appropriate learning strategies and instructional support are needed—approaches that actively engage students and provide meaningful learning experiences in mathematics classrooms.

One instructional model considered relevant to address these issues is Problem-Based Learning (PBL). PBL is a learning model that uses contextual problems as the starting point of instruction, encouraging students to identify problems, gather information, develop solutions, and reflect on the learning process

(Ansya & Salsabilla, 2025; Muhtadi & Hukom, 2025; Titania & Marsigit, 2025). In mathematics education, PBL allows students to construct conceptual understanding through investigation and discussion rather than merely receiving information from teachers.

Previous empirical studies have reported that the implementation of PBL in mathematics learning contributes positively to various mathematical abilities, such as problem-solving skills (Ahdhianto et al., 2020; Dorimana et al., 2022; Shongwe, 2024), critical thinking skills (Ahdhianto et al., 2020; Hairun et al., 2020; Rahman et al., 2021; Selvy et al., 2020), and mathematical communication skills (Hidayati et al., 2020). PBL has also been implemented across different educational levels, including elementary school (Ahdhianto et al., 2020), junior high school (Kamid et al., 2021; Ramli et al., 2020), and senior high school (Ogunsola et al., 2021; Zaenuri et al., 2020). In addition, several studies integrated various instructional supports, such as student worksheets (Rahman et al., 2021), e-modules (Dorimana et al., 2022), and technology-assisted learning media (Rahman et al., 2021; Selvy et al., 2020).

Although studies on PBL in mathematics education have been widely conducted, most of them focus on evaluating the effectiveness of PBL on specific learning outcomes within a single educational level or context, such as problem-solving skills in senior high school or critical thinking in junior high school. What remains unexplored is a comprehensive picture of how PBL is implemented across different educational levels, mathematical topics, and instructional supports, as well as how the research trends in this area have developed over time. Existing reviews trend to summarize outcomes narratively without systematically mapping implementation patterns and methodological trends across studies, making it difficult to identify which aspects of PBL research remain underexplored. A Systematic Literature Review (SLR) is therefore an appropriate approach to address this gap, as it enables a transparent, structured, and replicable process of identifying, screening, and synthesizing empirical findings from multiple studies, following an explicit seeks to provide a more comprehensive synthesis than previous narrative summaries, both in terms of implementation practices and research trends of PBL in school mathematics education. Based on these considerations, this study aims to conduct a Systematic Literature Review (SLR) of research articles discussing the implementation of Problem-Based Learning in school mathematics education. The research question of this study are formulated to discover how PBL is implemented in school mathematics learning based on previous studies an to identify the research trends related to its implementation.

METHOD

This study adopted the methodology of the Systematic Literature Review (SLR), whereby findings from past studies were identified, analyzed, and synthesized systematically (Kitchenham, 2004). The SLR methodology was chosen because it would provide a thorough understanding of the implementation practices and research trends of Problem-Based Learning (PBL) in mathematics instruction, using empirical literature as its basis. The process adopted in this systematic review adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) model, which includes four main steps: identification, screening, eligibility, and inclusion, ensuring that the selection of articles was transparent and consistent. In order to ascertain the relevancy of the literature, inclusion and exclusion criteria were formulated, as shown in Table 1.

Table 1. Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
Discusses Problem-Based Learning (PBL) as the main instructional model.	Doesn't discuss Problem-Based Learning or only mentions it briefly.
Conducted within the context of school mathematics learning.	Not conducted within the context of school mathematics learning.
Focuses on the implementation of PBL, such as learning stages, teacher and student roles, or learning media.	Not an empirical study.
Empirical research using qualitative, quantitative, or mixed methods.	Full-text article is unavailable.
Published in scientific journals and available in full-text form.	Not relevant to the research questions.
Written in English.	Studies published in languages other than English.

To ensure transparency, reproducibility, and methodological rigor, the literature search was conducted following the Preferred Reporting Items for Systematic Reviews and Meta Analyses (PRISMA) guidelines. The search process was performed using Publish or Perish (PoP) software, which served as the search interface for the Scopus database. Scopus was selected because it is one of the most comprehensive and reputable multidisciplinary databases, providing access to high quality peer-reviewed publications in education and related disciplines. The search strategy was designed using Boolean operators to identify studies specifically investigating the implementation of Problem-Based Learning (PBL) in mathematics education. The Boolean search string applied was: "Problem-Based Learning" and "Mathematics Education".

The search was performed in the Title, Abstract, and Keywords fields to ensure that the retrieved publications explicitly addressed both concepts. The Boolean operator "and" was used to retrieve only studies containing both keywords simultaneously, thereby increasing the relevance of the search results. Double quotation marks (" ") were employed to search for the exact phrases "Problem-Based Learning" and "Mathematics Education", preventing the database from retrieving articles containing the individual words separately in unrelated contexts. Consequently, only studies that explicitly discussed Problem-Based Learning within the context of mathematics education were identified.

To further improve the relevance and quality of the retrieved studies, several search restrictions were applied. The search was limited to publications released between 2020 and 2025, enabling the review to capture recent developments and contemporary evidence regarding the implementation of Problem-Based Learning in mathematics education. Only peer-reviewed journal articles written in English were considered eligible. Conference proceedings, book chapters, review papers, editorials, notes, letters, and other non journal publications were excluded during the search process to ensure methodological consistency and maintain the quality of the evidence included in the review.

The initial search identified 200 records from the Scopus database. Since only one database was searched, no duplicate records were identified; therefore, 0 duplicate records were removed before the screening process. Consequently, all 200 records proceeded to the tittle and abstract screening stage. During the screening stage, each record was evaluated according to the predefined inclusion and exclusion criteria presented in Table 1. A total of 155 records were excluded because they did not meet the eligibility criteria. Most of these studies did not primarily focus on the implementation of Problem-Based Learning in mathematics education, while others investigated different instructional approaches, educational interventions, or topics unrelated to the objectives of this systematic literature review. As a result, 45 articles remained for full-text assessment.

All 45 full text articles were successfully retrieved, resulting in no reports not retrieved (n=0). Each article was then carefully assessed for eligibility based on the predefined inclusion and exclusion criteria, including relevance to the research objectives, educational context, research design, publication language, and the availability of sufficient information for data extraction.

Following the full text assessment, 37 articles were excluded for several reasons. Some studies were excluded because they were not conducted within the field of mathematics education despite discussing Problem-Based Learning. Other studies employed non empirical research designs, such as literature reviews, theoretical papers, or conceptual articles, which did not provide primary empirical evidence. Several articles were excluded because their findings did not directly address the research questions concerning the implementation of Problem-Based Learning in mathematics education. Additional exclusions were made for studies published in languages other than English or those that did not provide sufficient information for detailed analysis.

After the eligibility assessment, 8 studies met all inclusion criteria and were included in the final systematic literature review. These studies provided empirical evidence regarding the implementation of Problem-Based Learning in mathematics education across various educational levels, mathematical topics, research methodologies, and reported learning outcomes. The complete study selection process is presented in the PRISMA flow diagram shown in Figure 1**.**

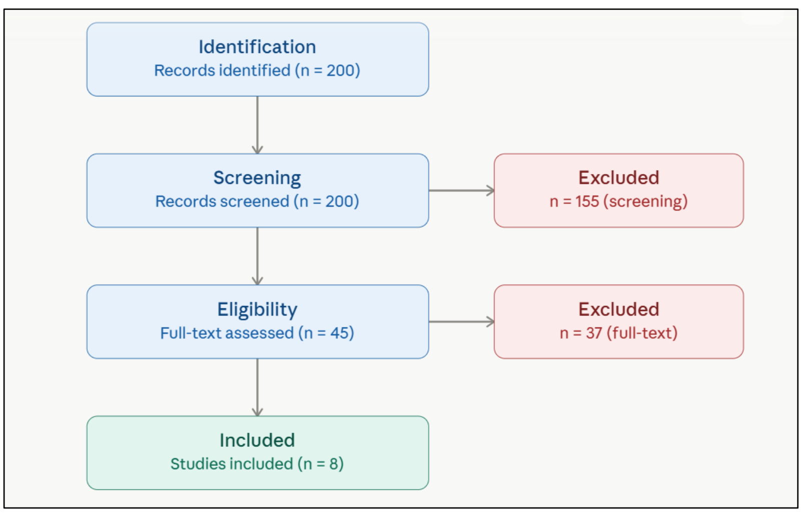

Figure 1. PRISMA flow diagram

RESULTS AND DISCUSSION

Using the PRISMA approach in selecting the articles, eight articles were found to meet the set inclusion criteria and analyzed to answer the research questions of this study. Results indicate that the application of Problem-Based Learning (PBL) in teaching mathematics follows a fairly similar pattern, although there are differences in problem scenarios, learning media, and approaches used in each study. The relatively small number of included studies reflects the strict application of the inclusion and exclusion criteria in Table 1, particularly the requirement that PBL be examined as the primary instructional focus within an empirical, school-level mathematics context; among the 45 full-text articles assessed for eligibility, most were excluded because they addressed PBL only briefly, used non-empirical designs, lacked full-text availability, or were not directly relevant to the research questions of this review.

RQ 1: Application of Problem-Based Learning in School Mathematics Education

From the analysis of the eight articles, it can be inferred that the implementation of Problem-Based Learning (PBL) in school mathematics education exhibits both consistent instructional characteristics and contextual variations. Although the studies were conducted across different educational levels, mathematics topics, and learning environments, they shared a common pedagogical framework. In general, PBL was implemented through several core stages, namely problem orientation, group organization, inquiry or investigation, presentation of solutions, and reflection or assessment. These stages consistently positioned students as active learners who collaboratively explored authentic mathematical problems while teachers acted as facilitators throughout the learning process.

Despite these similarities, each study adapted the implementation of PBL according to its specific instructional context. Variations were identified in the problem scenarios presented to students, the mathematics topics being taught, the educational level of participants, the instructional materials used, and the integration of learning technologies. Several studies employed contextual problems related to students' daily lives, local culture, or STEM applications, while others incorporated technology such as GeoGebra, TPACK-based instruction, student worksheets, or self-directed learning activities to support mathematical investigation. These findings indicate that although the instructional procedures of PBL remain relatively consistent, its implementation is sufficiently flexible to accommodate diverse classroom contexts and learning objectives.

To provide a clearer overview of the implementation patterns identified across the reviewed studies, Table 2 summarizes the educational level, mathematics topic, PBL stages, and distinctive characteristics of each article. This comparison illustrates both the consistency of the core PBL stages and the contextual variations in their implementation.

Table 2. Characteristics of PBL Implementation based on the Reviewed Articles

	Article	Educational Level	Mathematics Topic	PBL Stages	Distinctive Characteristics
1	(Ahdhianto et al., 2020)	Elementary School	Distance, Speed, and Rate	Problem orientation -> group organization -> investigation -> presentation -> analysis and evaluation	Real-world problems, small group discussion, learning reflection.
2	(Kamid et al., 2021)	Junior High School	Social Arithmetic	Problem orientation -> brainstorming -> investigation -> presentation -> practice	Jambi cultural context, TPACK integration.
3	(Dorimana et al., 2022)	Senior High School	Sequences, Logarithms, Exponents	Problem presentation -> brainstorming -> group organization -> self-directed investigation -> presentation -> application	Self-directed learning (SDL), textbook-based.

4	(Selvy et al., 2020)	Senior High School	Geometric Transformation	Problem orientation -> group organization -> investigation -> presentation -> analysis	GeoGebra integration, visualization and discovery activities, animation.
5	(Hidayati et al., 2020)	Senior High School	Statistics	Problem orientation -> group organization -> investigation -> presentation -> evaluation	TPACK integration, mathematical communication focus, contextual problems.
6	(Shongwe, 2024)	Senior High School	Slope, Gradient, Energy (STEM)	Problem orientation -> group discussion -> investigation -> experimentation -> presentation -> evaluation	STEM-based activities, experimental tasks, written reports.
7	(Rahman et al., 2021)	Senior High School	Linear Programming	Problem orientation -> group organization -> investigation -> experimentation -> presentation -> evaluation	GeoGebra, student worksheets (LKS).
8	(Ramli et al., 2020)	Senior High School	Pythagorean Theorem, Geometric Transformation, Statistics	Clarifying -> defining -> analyzing -> restructuring -> goals -> individual -> reporting	Multiple mathematics topics, collaborative problem-solving activities.

To complement the narrative synthesis in Table 2, Figure 2 presents the distribution of the eight reviewed articles across educational levels. The chart shows that senior high school settings accounted for the majority of the studies, while elementary and junior high school contexts were each represented by only one study, underscoring the uneven attention PBL research has received across educational levels, a pattern discussed further under RQ 2.

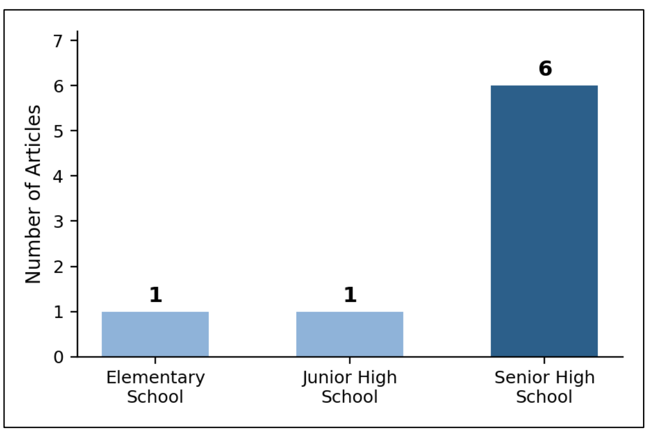

Figure 2. Distribution of the Eight Reviewed Articles by Educational Level

Based on the synthesis, the implementation of Problem-Based Learning (PBL) reflects a student-centered learning approach that emphasizes active knowledge construction through contextual problem solving. In the problem orientation stage, students were introduced to authentic problems related to daily life, local culture, STEM, and ethnomathematics contexts. This stage is significant because it positions learning as a process that begins with real-world problems rather thandirect formula instruction. From a constructivist perspective, the teacher's role as a facilitator rather than a knowledge transmitter aligns with the theory of Lev Vygotsky, particularly the concept of scaffolding, where students are guided to independently explore possible solutions. Critically, the effectiveness of this stage largely depends on the quality of the problems designed by the teacher. Problems that are too simple may fail to stimulate critical thinking, while excessively complex problems may reduce students' motivation and engagement.

The group organization stage demonstrates the collaborative nature of PBL, where students work together to discuss ideas, exchange perspectives, and construct conceptual understanding collectively. This process supports the development of social interaction and collaborative learning skills, which are essential in modern mathematics education. However, the synthesis does not critically address potential challenges within group work, such as unequal participation, passive learners, or dominant students controlling discussions. These issues indicate that effective classroom management and facilitation skills are necessary to ensure that collaboration genuinely contributes to meaningful learning rather than becoming merely procedural group activity.

Furthermore, the investigation stage represents the core of PBL implementation because students actively engage in higher-order thinking processes. During this stage, students gathered information, applied various strategies, developed mathematical models, and utilized technological tools such as GeoGebra to solve problems. The integration of STEM, TPACK, and ethnomathematics frameworks indicates that PBL is flexible and adaptable to interdisciplinary learning approaches. From a critical perspective, this stage promotes analytical, evaluative, and creative thinking skills, which are central components of twenty-first-century competencies. Nevertheless, the successful implementation of this stage requires adequate technological support, sufficient instructional time, and teachers who possess strong pedagogical and technological competencies. Without these supports, the investigation process may not function optimally, particularly in schools with limited educational resources.

In the presentation stage, students communicated their findings and explained their mathematical reasoning to peers, which contributed to the development of mathematical communication, confidence, and logical argumentation skills. This stage is pedagogically important because explaining solutions encourages students to reflect on and justify their own thinking processes. Peer responses and questioning also create opportunities for conceptual clarification and deeper understanding. However, not all students may feel confident presenting their ideas publicly, especially those with low self-confidence or mathematics anxiety. Therefore, teachers must create a supportive classroom environment that encourages respectful discussion and active participation from all students.

Finally, the reflection and evaluation stage highlights the importance of metacognitive development in PBL. Through reflection, students evaluated the effectiveness of their strategies, analyzed errors, and summarized mathematical concepts learned during the activity. This stage supports students in becoming more aware of their own thinking processes and learning strategies, which is essential for self-regulated learning. Critically, many educational practices tend to emphasize final answers rather than reflective thinking processes. As a result, the potential of reflection to strengthen deep conceptual understanding and metacognitive awareness is often underutilized. Therefore, reflection should not merely function as a concluding activity, but as an integral component that helps students internalize knowledge and transfer mathematical understanding into different contexts.

Overall, the synthesis indicates that Problem-Based Learning is not simply a procedural teaching method consisting of five stages, but a comprehensive pedagogical approach aimed at developing critical thinking, collaboration, communication, problem-solving, and metacognitive skills. Nevertheless, the effectiveness of PBL is strongly influenced by the quality of problem design, teacher facilitation, classroom management, students' readiness, and the availability of technological and instructional support. Therefore, successful PBL implementation requires careful instructional planning and pedagogical competence to ensure that learning becomes meaningful, reflective, and intellectually engaging.

RQ 2: Research Trends Associated with Problem-Based Learning in Mathematics Teaching

The subsequent analysis concentrated on the research trends connected with the application of PBL in school mathematics teaching, including their distribution among educational levels, research methods, results, and the combination of PBL with other methods or tools.

To examine methodological and outcome-related trends more closely, Table 3 summarizes the research method and the primary reported outcome of each reviewed article, based on the original published studies.

Table 3. Research Method and Primary Reported Outcome of the Reviewed Articles

	Article	Research Method	Primary Reported Outcome
1	(Ahdhianto et al., 2020)	Quasi-experimental (pre-test/post-test control group)	Problem-solving skills; critical thinking skills
2	(Kamid et al., 2021)	Mixed-method, quasi-experimental	Learning effectiveness of ethnomathematics-TPACK integration
3	(Dorimana et al., 2022)	Quasi-experimental (one-group pre-test/post-test)	Problem-solving abilities
4	(Selvy et al., 2020)	Experimental (randomized pre-test/post-test control group)	Creative thinking; motivation
5	(Hidayati et al., 2020)	Classroom Action Research (CAR)	Mathematical communication skills; learning interest
6	(Shongwe, 2024)	Quasi-experimental (mixed quantitative-qualitative)	Mathematical problem-solving beliefs
7	(Rahman et al., 2021)	Quasi-experimental (one-group pre-test/post-test)	Critical thinking skills
8	(Ramli et al., 2020)	Quasi-experimental (nonrandomized control group, post-test)	Mathematical values

Figure 3 and Figure 4 present the distribution of research methods and reported outcomes across the eight studies, based on the classification in Table 3.

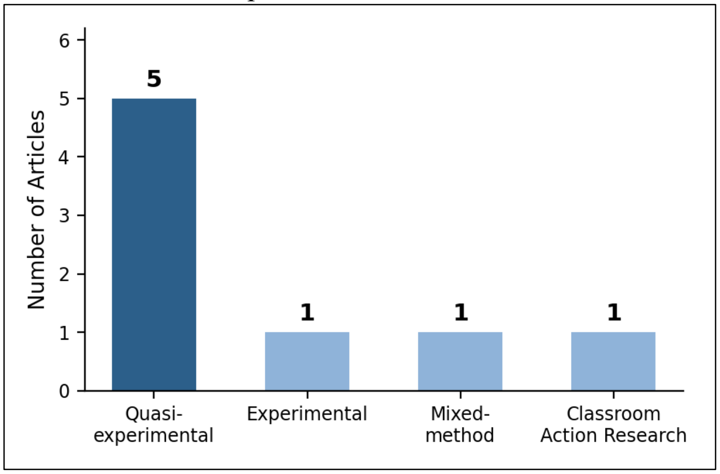

Figure 3. Distribution of Research Methods Used in the Reviewed Articles

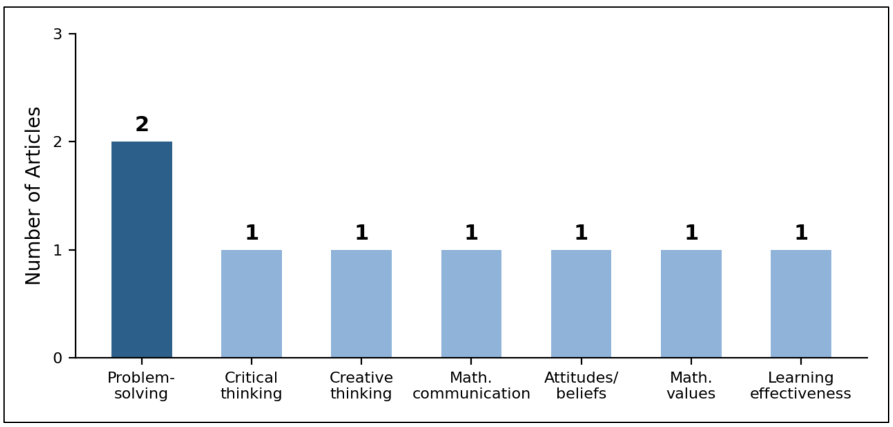

Figure 4. Distribution of Primary Reported Outcomes in the Reviewed Articles

In terms of educational level distribution, studies examining the use of PBL in mathematics education have predominantly focused on senior high schools. Out of the eight papers reviewed, most had been conducted at the senior high school level, while a few studies had been carried out at junior high schools and elementary schools. High school students typically have more advanced skills in abstract thought and logical reasoning, which equip them to engage in problem-based learning tasks that require complex investigation, analysis, and solution-finding. Moreover, high school topics like functions, calculus, statistics, and analytic geometry present greater complexity and are thus more frequently examined in PBL research. In contrast, research at the elementary level remains sparse because younger children are in the early stages of cognitive development and require a higher degree of teacher guidance, supportive learning media, and simpler problem settings.

Regarding methodological approaches, the most dominant research method used within mathematics learning contexts was the quasi-experimental method. Among the eight analyzed articles, most studies applied quasi-experimental designs, while experimental, mixed-method, and classroom action research (CAR) approaches were used less frequently. These findings indicate that research on PBL in mathematics learning has primarily focused on examining the effectiveness and impact of the learning model through group comparisons, whereas other holistic research approaches remain limited.

Analysis of research outcomes revealed that mathematical problem-solving skills and critical thinking skills emerged as the dominant focuses in the analyzed studies. In contrast, other outcomes, such as creative thinking, mathematical communication skills, attitudes and beliefs toward mathematics, and mathematical values, were investigated less frequently. This indicates that research on PBL in mathematics learning tends to emphasize the development of higher-order cognitive skills over affective or communicative outcomes.

Lastly, concerning forms of PBL integration, the implementation of PBL in mathematics education was most commonly conducted as standalone PBL without integration with other instructional approaches or learning technologies. Although several studies integrated PBL with digital technologies (like GeoGebra), other forms of integration, such as STEM-based PBL, PBL combined with the TPACK framework, and ethnomathematics-oriented PBL, were still relatively limited.

Discussion

The synthesis of findings indicates that PBL has been implemented relatively consistently in mathematics education, although current research trends remain concentrated within certain contexts. The consistency of the core stages reflects a shared understanding among researchers regarding the fundamental principles of PBL as a student-centered model. The variations found in problem contexts, technology integration, and supporting approaches such as STEM, TPACK, and ethnomathematics demonstrate that PBL is flexible and adaptable to various learning needs (Rehman et al., 2024; Yildirim & Baur, 2025).

However, this flexibility has not been fully reflected in current research trends. The dominance of senior high school contexts is closely related to the characteristics of PBL, which require abstract thinking, complex problem-solving, and independent learning skills (Chen et al., 2024; Yuliana & Suwito, 2024). The limited number of studies at the elementary and junior high school levels suggests that the adaptation of PBL for younger learners has not yet become a major research focus. Furthermore, the methodological tendency toward quasi-experimental approaches shows that most PBL studies focus more on measuring learning effectiveness than on exploring internal learning mechanisms, interactions, and thinking strategies during the process.

Finally, while there is a strong alignment between PBL characteristics and higher-order cognitive abilities (Darwis et al., 2024; Loyens et al., 2023; Mustakim et al., 2024), the limited attention given to outcomes like mathematical communication, attitudes, beliefs, and mathematical values suggests that the broader impacts of PBL have not yet been explored comprehensively. Innovative explorations connecting PBL with local contexts, educational technology, and contemporary pedagogical frameworks remain an open area for future research. This pattern echoes earlier systematic reviews conducted outside the mathematics-specific context; Loyens et al. (2023), for example, similarly found that PBL and project-based learning environments emphasize higher-order and critical-analytic thinking outcomes more consistently than affective or social dimensions, while Darwis et al. (2024) reported a comparable skew toward cognitive outcomes across the broader PBL literature. The present review extends these observations by showing that a similar imbalance persists specifically within school mathematics education, suggesting that the tendency to prioritize cognitive outcomes over affective and communicative ones is not unique to mathematics but may reflect a wider trend in PBL research. In this sense, the theoretical contribution of this review lies in mapping how PBL's implementation stages and research priorities manifest specifically within mathematics classrooms, offering a subject-specific complement to the more generalized syntheses provided by prior reviews.

Limitations of the Review

This review is subject to several limitations. First, the literature search was restricted to the Scopus database and to articles published in English between 2020 and 2025, which may have excluded relevant studies indexed elsewhere or published in other languages. Second, the final synthesis was based on only eight articles; although this number resulted from a rigorous and transparent screening process following the PRISMA framework, it nonetheless limits the extent to which the findings can be generalized across the broader population of PBL research in mathematics education. Third, this review relied on a narrative synthesis rather than a meta-analysis, meaning that the strength of PBL's effects on learning outcomes could not be statistically quantified or compared across studies. Future reviews may benefit from a broader multi-database search strategy and, where sufficient quantitative data are available, a meta-analytic approach to complement the descriptive patterns identified here.

CONCLUSION

Drawing from the results of this Systematic Literature Review (SLR), it can be concluded that Problem-Based Learning (PBL) has been widely and consistently applied within mathematics teaching practices through several core stages, namely problem orientation, student organization, investigation, presentation, and reflection or evaluation. This consistency reflects the strong conceptual foundation of PBL as an instructional approach that promotes students' active participation during learning activities. The novelty of this review lies in its integrative focus on both the implementation stages and the research trends of PBL specifically within school mathematics education, an angle that has not been jointly addressed in prior reviews examining PBL more broadly across disciplines. However, the research trends indicate that studies on PBL are still largely dominated by senior high school contexts, quasi-experimental approaches, and a focus on higher-order cognitive outcomes, particularly problem-solving and critical thinking

skills. In contrast, studies conducted at elementary and junior high school levels, investigations of learning processes, non-cognitive outcomes, and the integration of PBL with technology and contextual approaches remain relatively limited, indicating opportunities for further research development. For educators, these findings highlight the importance of designing PBL implementation by considering problem contexts, student characteristics, and technology integration to improve learning quality. For researchers, this review recommends (a) conducting more studies at the elementary and junior high school levels, where research on PBL remains scarce; (b) employing process-oriented and qualitative methodologies, such as classroom discourse analysis or design-based research, to examine how students engage with each PBL stage rather than relying solely on pre-test/post-test measures; and (c) broadening the range of outcomes studied to include mathematical communication, attitudes and beliefs, and mathematical values alongside problem-solving and critical thinking, so as to build a more holistic understanding of PBL's impact in mathematics education. The methodological and contextual limitations of this review, outlined earlier in the Discussion section, should also be taken into account when interpreting and building upon these conclusions.

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