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Problem-Based Learning and Differentiated Instruction in Elementary Mathematics: A Systematic Literature Review of Students' Problem-Solving

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ABSTRACT

Objective: This systematic literature review aims to analyze research trends related to the implementation of Problem-Based Learning (PBL) and Differentiated Instruction (DI) in elementary mathematics education, particularly in relation to students' problem-solving abilities. **Method:** The review followed the PRISMA protocol by systematically searching the Scopus database. From 92 identified records, 24 empirical studies published between 2021 and 2024 met the inclusion criteria. The selected studies were analyzed based on research design, instructional approach, and problem-solving focus.. **Results:** The findings indicate that both PBL and DI independently contribute positively to students' mathematical problem-solving skills, including reasoning, strategy development, and higher-order thinking. However, most studies examined PBL and DI separately, while only a limited number explicitly integrated both approaches within a single instructional framework. **Novelty:** This review highlights a significant research gap regarding the explicit integration of PBL and DI in elementary mathematics learning, emphasizing the need for instructional models that simultaneously address problem-centered learning and learner diversity.

INTRODUCTION

Mathematics learning in elementary schools plays a fundamental role in fostering students' logical reasoning, analytical thinking, and problem-solving abilities, which are essential competencies for lifelong learning and participation in a knowledge-based society (Avcu & Avcu, 2010; OECD, 2019). However, international and national assessments consistently report that many elementary students experience difficulties in understanding mathematical concepts, particularly in applying abstract ideas to real-life problem situations (OECD, 2019). These challenges are often associated with teacher-centered instructional practices, limited student engagement, and insufficient attention to individual differences in students' readiness, interests, and learning profiles (Lekahena & Naibaho, 2024)

From a sociocultural perspective, learning is most effective when instruction is aligned with students' Zone of Proximal Development (ZPD) and supported through appropriate scaffolding, as proposed by Vygotsky (Shabani et al., 2010). This perspective underscores the need for adaptive and student-centered instructional approaches that actively engage learners while accommodating diverse learning needs. In elementary mathematics education, such approaches are particularly important given the wide variation in students' prior knowledge, cognitive development, and learning pace.

Problem-Based Learning (PBL) has been widely recognized as an instructional approach that promotes active learning through engagement with authentic and meaningful problems. By situating learning in real-world contexts, PBL encourages students to develop higher-order thinking skills, including analysis, synthesis, and

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evaluation, while fostering collaboration and self-directed learning (Hmelo-Silver, 2004; Hung, 2015; Lin et al., 2024). Empirical studies have demonstrated that PBL can enhance students' conceptual understanding, problem-solving skills, and learning motivation in mathematics classrooms (Boye & Agyei, 2023; Pimdee et al., 2024; Tursynkulova et al., 2023). Nevertheless, the effectiveness of PBL may vary depending on students' initial abilities, self-regulation skills, and learning characteristics, indicating the need for instructional adjustments to address learner diversity.

Differentiated Instruction (DI) offers a pedagogical framework for responding to such diversity by adapting instructional content, learning processes, and assessment products based on students' readiness, interests, and learning profiles (Tomlinson, 2017; Tomlinson & Jarvis, 2023). Research indicates that differentiated instruction supports inclusive and equitable learning environments by enabling all students to engage meaningfully with mathematical tasks at appropriate levels of challenge (Dack, 2018; Maphumulo & Biccard, 2024; Santangelo & Tomlinson, 2012). In elementary mathematics classrooms, DI allows teachers to provide varied scaffolding and learning pathways, thereby supporting both struggling learners and high-achieving students.

The integration of Problem-Based Learning and Differentiated Instruction has emerged as a promising instructional strategy for addressing both cognitive and individual learner needs in mathematics education. While PBL provides rich, problem-centered learning experiences that stimulate critical and reflective thinking, DI ensures that instructional support is responsive to students' diverse characteristics (Mills et al., 2014; Robinson et al., 2014). Previous studies suggest that combining these approaches can enhance conceptual understanding, increase learning motivation, and promote students' independence in mathematical problem-solving (Aba-Oli et al., 2024).

Despite the growing body of research on PBL and DI, existing studies predominantly examine these approaches in isolation. Systematic investigations that explicitly explore their integrated implementation in elementary mathematics classrooms remain limited, particularly in the form of comprehensive literature reviews that synthesize conceptual frameworks, instructional practices, and learning outcomes. This gap indicates a need for a systematic synthesis of existing research to clarify how PBL and DI can be effectively combined to support elementary students' mathematical problem-solving abilities.

Research Objectives

Therefore, this systematic literature review aims to synthesize empirical evidence on the implementation of Problem-Based Learning and Differentiated Instruction in elementary mathematics education using the PRISMA framework (Tugwell & Tovey, 2021). Specifically, this review seeks to: (1) identify research trends related to the integration of PBL and DI; (2) examine reported impacts on students' mathematical problem-solving skills; and (3) highlight gaps and implications for future research and instructional practice.

RESEARCH METHOD

Data analysis was conducted using a thematic synthesis approach (Tugwell & Tovey, 2021). This process involved several stages: (1) thoroughly reading all selected articles to understand their context and main findings; (2) conducting *open coding* by identifying meaningful units related to the implementation of Problem-Based Learning (PBL), Differentiated Instruction (DI), and students' mathematical problem-solving abilities;

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(3) grouping similar codes into initial categories; (4) developing overarching themes based on the relationships among categories, such as instructional characteristics, differentiation strategies, and impacts on problem-solving abilities; and (5) reviewing and refining the themes to ensure consistency and accurate representation of the data. This process was carried out iteratively to enhance the validity and depth of the synthesis. To enhance analytical rigor, the coding and theme development processes were conducted systematically using a constant comparison technique across studies (Tugwell & Tovey, 2021). The selection process is summarized in the PRISMA flow diagram (Figure 1).

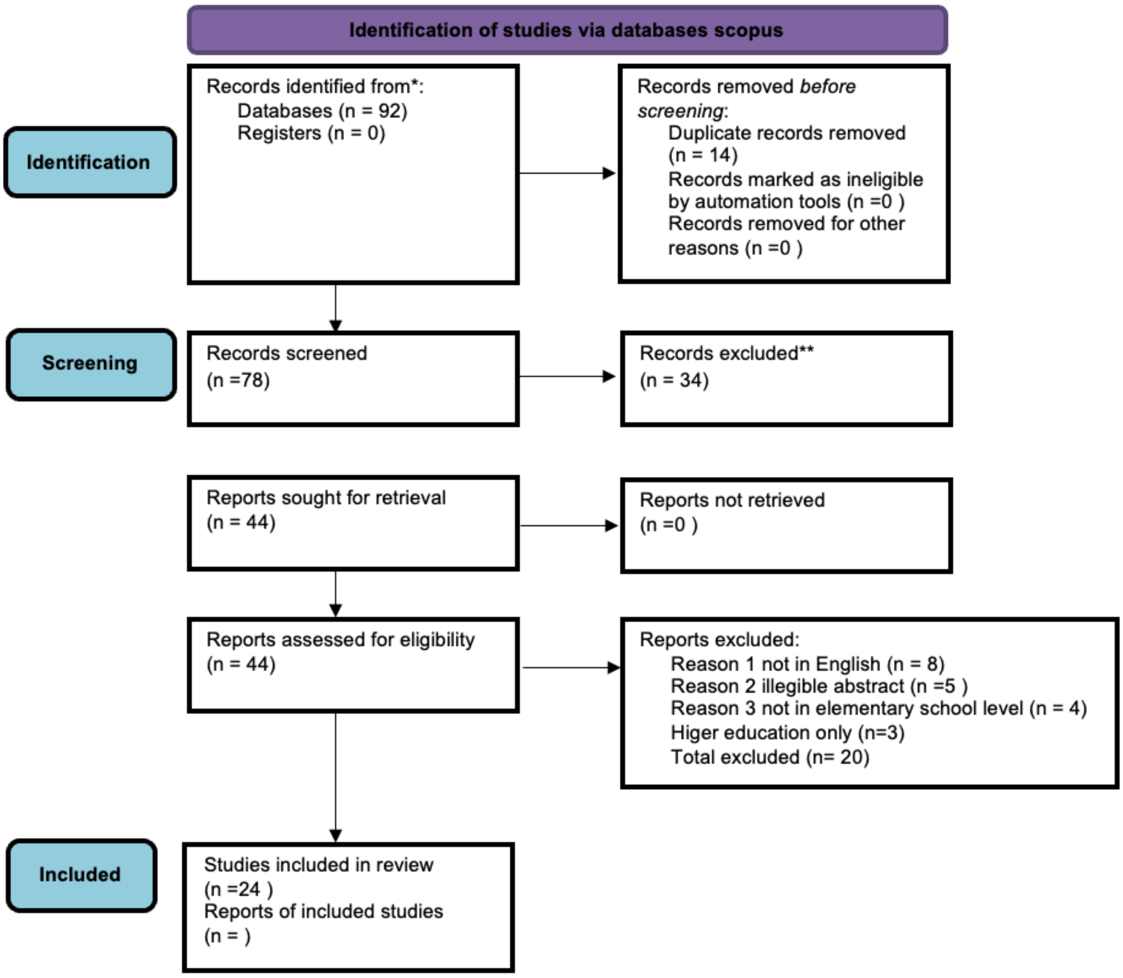

Figure 1. PRISMA Flow Diagram of the Study Selection Process

RESULTS AND DISCUSSION

Results

The results of this systematic literature review are synthesized based on 24 selected studies that examined the roles of Problem-Based Learning (PBL) and Differentiated Instruction (DI) in supporting students' mathematical problem-solving abilities at the elementary school level. As summarized in Table 1, the reviewed studies employed diverse research designs, with experimental and quasi-experimental approaches dominating the literature.

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Table 1. Concise Synthesis of Included Studies

Nu	Author(s) & Year	Research Design	PBL	DI	Problem-Solving Focus
1	Hubbard (2021)	Quasi-experimental	–	✓	Mathematical reasoning
2	Götz et al. (2022)	Experimental	✓	–	Error-based problem solving
3	Melesse et al. (2022)	Mixed-method	–	✓	General problem solving
4	Jia et al. (2023)	Experimental	✓	✓	Mathematical problem solving
5	Goltsiou et al. (2023)	Quasi-experimental	✓	✓	Strategy use
6	Wong et al. (2023)	Survey	–	✓	Cognitive skills
7	Strogilos et al. (2023)	Case study	–	✓	Inclusive problem solving
8	Russo et al. (2024)	Experimental	✓	✓	Mathematical reasoning
9	Cheng et al. (2024)	Experimental	✓	✓	Mathematical problem solving
10	Bi et al. (2024)	Mixed-method	–	✓	Strategic thinking
11	Hu et al. (2024)	Quasi-experimental	✓	✓	Problem-solving performance
12	Johler et al. (2024)	Qualitative	–	✓	Cognitive engagement
13	Žakelj et al. (2024)	Experimental	✓	–	Algebraic problem solving
14	Yunaini et al. (2024)	Quasi-experimental	–	✓	Mathematical problem solving
15	Smith et al. (2021)	Experimental	✓	–	Strategy development
16	Lee et al. (2021)	Mixed-method	✓	✓	Problem-solving stages
17	Fernández et al. (2022)	Experimental	✓	–	Conceptual problem solving
18	Rahman et al. (2022)	Quasi-experimental	–	✓	Problem-solving outcomes
19	Novak et al. (2023)	Experimental	✓	✓	Higher-order thinking
20	Silva et al. (2023)	Mixed-method	✓	–	Collaborative problem solving
21	Park et al. (2024)	Experimental	✓	✓	Problem-solving ability
22	Ahmed et al. (2024)	Quasi-experimental	–	✓	Mathematical problem solving
23	Lestari et al. (2023)	Experimental	✓	✓	Problem-solving support
24	Oliveira et al. (2024)	Experimental	✓	✓	Mathematical problem solving

Note: *A check mark (✓) indicates that the instructional approach—Problem-Based Learning (PBL) or Differentiated Instruction (DI)—was explicitly implemented in the study; a dash (–) indicates that the approach was either not applied or not reported in the study.*

In terms of instructional approaches, a considerable number of studies incorporated problem-based or problem-centered learning, either explicitly or implicitly. Several studies utilized authentic, contextual, or ill-structured problems as the core learning activities, aligning with key principles of PBL. These studies consistently reported improvements in mathematical reasoning, strategy development, and conceptual understanding, suggesting that engaging students in problem-centered learning environments supports deeper mathematical thinking (Aba-Oli et al., 2024; Boye & Agyei, 2023; Hmelo-Silver, 2004; Hung, 2015).

Differentiated instruction was prominently represented across the reviewed studies, often implemented through strategies such as task variation, flexible grouping, adaptive scaffolding, and individualized support. The findings indicate that DI contributes positively to students' engagement and accessibility to mathematical problem-solving tasks, particularly for learners with diverse readiness levels and prior knowledge. Studies focusing on DI frequently emphasized improvements in problem-solving performance, cognitive engagement, and strategic thinking (Johnsen et al., 2020; Maphumulo & Biccard, 2024; Santangelo & Tomlinson, 2012; Tomlinson, 2017; Tomlinson & Jarvis, 2023).

However, only a limited number of studies explicitly integrated both PBL and DI within a unified instructional framework. In most cases, the two approaches were examined independently or implicitly combined through problem-centered tasks accompanied by adaptive instructional support. This pattern suggests that while both

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approaches are widely recognized as effective, their systematic integration remains underexplored (Aba-Oli et al., 2024; Mills et al., 2014; Robinson et al., 2014).

It is important to note that this review was conducted using the Scopus database, which ensures a high standard of indexed and peer-reviewed publications. However, the inclusion of additional databases such as Web of Science or ERIC could further enhance the comprehensiveness and scientific robustness of the review. Therefore, future systematic reviews are encouraged to incorporate multiple databases to capture a broader range of relevant studies. To further explore research trends and thematic relationships, a bibliometric keyword co-occurrence analysis was conducted using VOSviewer (see Figure 2).

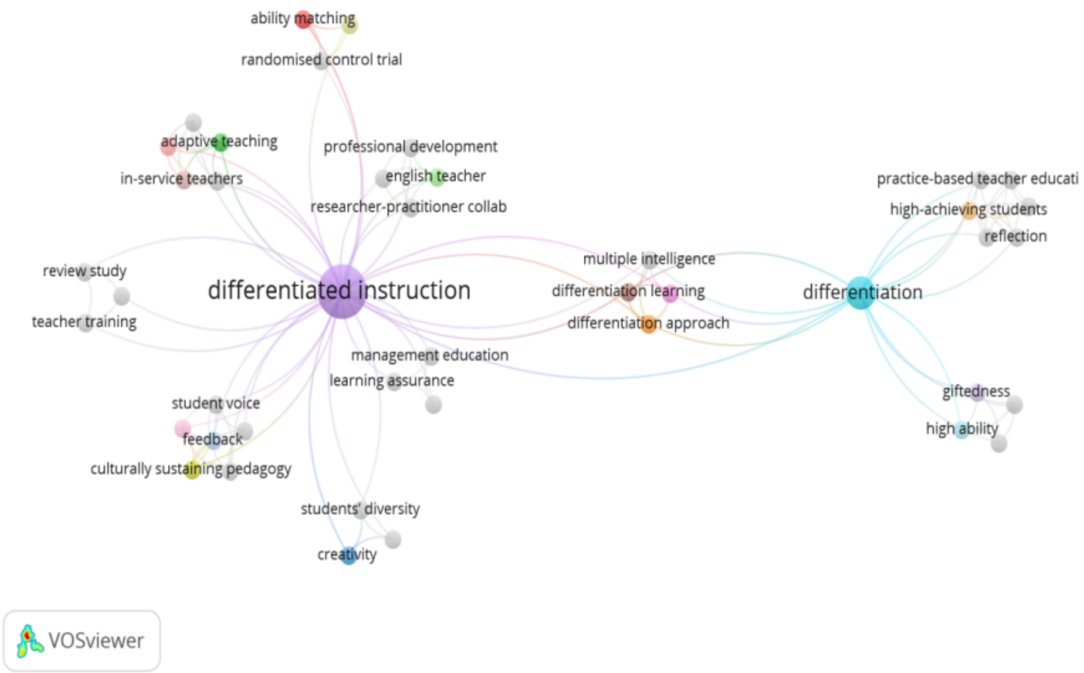

Figure 2. Visualization of Research Trends in Differentiated Instruction Using VOSviewer

The visualization reveals several dominant clusters, highlighting key themes such as problem-based learning, differentiated instruction, mathematics education, and problem-solving. The proximity and linkage strength between keywords indicate that PBL is strongly associated with active learning and higher-order thinking, whereas DI is more closely related to student diversity, instructional adaptation, and inclusive practices. Notably, the relatively weak linkage between PBL and DI suggests that their integration has not yet been extensively examined, reinforcing the findings of this review. In addition, Figure 1 presents the PRISMA flow diagram, which details the study selection process, including identification, screening, eligibility, and inclusion stages. The diagram illustrates how the initial pool of studies was systematically refined based on predefined criteria, ensuring transparency and methodological rigor.

Regarding problem-solving focus, the reviewed studies addressed a broad range of outcomes, including mathematical reasoning, strategy use, error-based problem solving, and higher-order thinking skills. Most studies emphasized the early cognitive stages of problem solving, particularly understanding the problem and devising solution strategies, which are closely associated with successful task completion

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(Aba-Oli et al., 2024; Avcu & Avcu, 2010). However, explicit attention to later stages-such as reflection, solution verification, and metacognitive evaluation-was comparatively limited.

This imbalance indicates that while students are often guided to produce correct answers, they are less frequently supported in evaluating their reasoning processes or reflecting on the effectiveness of their strategies. Such findings align with previous research suggesting that mathematics instruction tends to prioritize procedural accuracy over reflective and metacognitive processes (Slim, 2022).

Overall, the results demonstrate that both PBL and DI hold significant potential for enhancing elementary students' mathematical problem-solving abilities. However, their impact may not be fully optimized without instructional designs that explicitly incorporate all stages of the problem-solving process, including reflection and evaluation. This underscores the need for more integrative and structured instructional models that not only promote cognitive engagement but also foster students' metacognitive awareness in mathematical learning (Hmelo-Silver, 2004; Mills et al., 2014).

Discussion

The findings of this systematic literature review indicate that both Problem-Based Learning (PBL) and Differentiated Instruction (DI) contribute positively to the development of elementary students' mathematical problem-solving abilities. These approaches emphasize active learning, learner diversity, and meaningful engagement with mathematical tasks (Aba-Oli et al., 2024; Hmelo-Silver, 2004; Santangelo & Tomlinson, 2012). This result reinforces prior research demonstrating that problem-centered learning environments enhance students' mathematical reasoning, strategy development, and conceptual understanding by situating learning within meaningful and authentic contexts that reflect real-life problem situations (Hmelo-Silver, 2004; Hung, 2015; Savery, 2015). When students engage in solving real-world or ill-structured problems, they are encouraged to actively construct knowledge, justify their reasoning, and apply mathematical concepts flexibly—key components of effective mathematical problem solving and higher-order thinking skills(Jonassen, 2011; Mills et al., 2014; Shirali, 2014).

Studies focusing on Problem-Based Learning (PBL) consistently highlight its effectiveness in fostering higher-order thinking skills, including analysis, evaluation, and strategic reasoning. These skills are central to mathematical problem solving, particularly in supporting students' ability to reason, justify solutions, and make informed decisions (Pimdee et al., 2024; Savery, 2015; Wilder, 2015). Through collaborative inquiry and structured exploration, PBL encourages students to examine multiple solution pathways, evaluate the validity of their strategies, and refine their understanding through discussion and reflection. However, these benefits are highly dependent on the quality of task design and the level of instructional support provided (Hmelo-Silver, 2004; Johnsen et al., 2020; Mills et al., 2014).

Despite these strengths, the effectiveness of PBL is not uniform across learners. The results of this review suggest that students' prior knowledge, self-regulation abilities, and cognitive readiness significantly influence how effectively they engage with problem-based tasks (Hendrayana & Mutaqin, 2025; Loyens et al., 2023; Siregar et al., 2025). Learners with limited foundational knowledge or weaker self-regulation skills

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may experience cognitive overload when confronted with complex or ill-structured problems. This can hinder learning outcomes and reduce the potential benefits of PBL if adequate instructional support is not provided (Sweller, 2024; Wu et al., 2025).

These findings support previous assertions that PBL requires adaptive instructional support and systematic scaffolding to be effective for diverse learners, particularly in elementary mathematics contexts where students' cognitive development and learning readiness vary considerably (Hmelo-Silver, 2004; Hung, 2015; Tomlinson & Jarvis, 2023). Moreover, the limited emphasis on reflective and evaluative stages identified in this review reveals a clear misalignment with the competencies outlined in the OECD Learning Framework 2030, which highlights reflection, anticipation, and responsible action as essential dimensions of student learning. Within this framework, students are expected not only to solve problems but also to evaluate their thinking processes, reflect on outcomes, and adapt their strategies accordingly.

The relative absence of reflective and evaluative components in the reviewed studies indicates a gap between current instructional practices and internationally recognized learning competencies. This suggests that future implementations of PBL-particularly when integrated with Differentiated Instruction-should incorporate explicit metacognitive scaffolding to support students in monitoring, evaluating, and refining their problem-solving processes.

Several directions for future research emerge from these findings. First, there is a need for studies that explicitly design and test integrated PBL-DI instructional models, rather than examining the two approaches in isolation or through implicit combinations. Such studies should clearly define how problem design, differentiation strategies, and assessment practices are aligned within a coherent instructional framework. Second, future research should explore the role of metacognitive scaffolding within PBL-DI environments, particularly in supporting students' reflection, evaluation, and self-regulation during the problem-solving process. Third, longitudinal and mixed-method studies are needed to capture not only learning outcomes but also the processes through which students develop problem-solving abilities over time. Finally, future research should examine the implementation of PBL-DI across diverse educational settings, including different grade levels, cultural contexts, and levels of teacher expertise, to assess the scalability and adaptability of these approaches in real classroom practice.

Despite the contributions of this systematic literature review, several limitations should be acknowledged. First, this review relied solely on the Scopus database, which, although ensuring a high standard of peer-reviewed publications, may have limited the inclusion of relevant studies indexed in other databases such as Web of Science, ERIC, or Google Scholar. Second, the focus on published empirical studies may introduce publication bias, as studies reporting positive findings are more likely to be published than those with non-significant results. Third, variations in research design, sample characteristics, and instructional implementation across the included studies may affect the comparability of findings. This heterogeneity limits the extent to which generalized conclusions can be drawn regarding the effectiveness of integrated PBL and DI approaches. Finally, although this review employed thematic synthesis and bibliometric analysis, the interpretation of findings remains subject to the researcher's analytical perspective. Future studies may benefit from incorporating multiple reviewers or inter-

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rater validation to enhance the reliability of the synthesis process. These limitations should be considered when interpreting the findings of this review.

This systematic literature review highlights a significant gap in the current body of research regarding the integration of Problem-Based Learning (PBL) and Differentiated Instruction (DI) in elementary mathematics education. While both approaches have been shown to independently enhance students' mathematical problem-solving abilities, their combined implementation remains limited and insufficiently explored.

This gap is particularly critical in the context of elementary education, where students are at a foundational stage of cognitive development and require structured support to build essential problem-solving skills. At this level, learning experiences must not only engage students in meaningful problem contexts but also accommodate diverse readiness levels, learning paces, and developmental needs. The integration of PBL and DI, therefore, is not merely an instructional option, but a pedagogical necessity to ensure that all learners can access and meaningfully engage in mathematical thinking. This review underscores that effective mathematics instruction in elementary classrooms should extend beyond procedural understanding by incorporating authentic problem-solving experiences alongside adaptive instructional support. Furthermore, the limited emphasis on reflective and metacognitive processes identified in the literature indicates the need for more comprehensive instructional models that address all stages of problem solving. Therefore, future research should prioritize the development and empirical validation of integrated PBL-DI models specifically designed for elementary learners. Such models have the potential to support not only students' cognitive development but also their ability to think critically, reflectively, and independently in solving mathematical problems. Strengthening instructional approaches at the elementary level is essential, as it lays the foundation for students' long-term mathematical competence and lifelong learning.

CONCLUSION

This systematic literature review highlights a significant gap in the current body of research regarding the integration of Problem-Based Learning (PBL) and Differentiated Instruction (DI) in elementary mathematics education. While both approaches have been shown to independently enhance students' mathematical problem-solving abilities, their combined implementation remains limited and insufficiently explored. This gap is particularly critical in the context of elementary education, where students are at a foundational stage of cognitive development and require structured support to build essential problem-solving skills. At this level, learning experiences must not only engage students in meaningful problem contexts but also accommodate diverse readiness levels, learning paces, and developmental needs. The integration of PBL and DI, therefore, is not merely an instructional option, but a pedagogical necessity to ensure that all learners can access and meaningfully engage in mathematical thinking.

This review underscores that effective mathematics instruction in elementary classrooms should extend beyond procedural understanding by incorporating authentic problem-solving experiences alongside adaptive instructional support. Furthermore, the limited emphasis on reflective and metacognitive processes identified in the literature indicates the need for more comprehensive instructional models that address all stages of problem solving. Therefore, future research should prioritize the development and empirical validation of integrated PBL–DI models specifically

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