The Effectiveness of Problem-Based Learning on Mathematical Literacy: A Systematic Review in Elementary Education

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Abstract
Mathematical literacy is a fundamental competency, yet Indonesian students consistently underperform in international assessments. Traditional teacher-centered approaches prove inadequate for fostering students' ability to apply mathematical concepts in real-world contexts. This systematic literature review aimed to analyze the effectiveness of Problem-Based Learning (PBL) in enhancing mathematical literacy among elementary school students. Following PRISMA guidelines, a systematic search was conducted across multiple databases for publications from 2010 to 2024. Ten high-quality studies demonstrated consistent positive effects of PBL on mathematical literacy development, with interventions yielding 23-42% improvements in problem-solving and reasoning skills compared to traditional methods. This evidence supports PBL as a highly effective pedagogical approach for enhancing mathematical literacy. However, this review is limited to studies published within a specific timeframe and may not capture all relevant research. Future research should explore critical success factors and the long-term impact of PBL implementation in diverse contexts, including its influence on teacher development and curriculum reform.
Keywords: Problem-Based Learning, Mathematical Literacy, Elementary Education

Abstrak
Literasi matematika merupakan kompetensi mendasar, namun siswa Indonesia secara konsisten menunjukkan performa yang rendah dalam evaluasi internasional. Pendekatan tradisional yang berpusat pada guru terbukti tidak memadai untuk menumbuhkan kemampuan siswa dalam menerapkan konsep matematika pada konteks nyata. Tinjauan literatur sistematis ini bertujuan untuk menganalisis efektivitas *Problem-Based Learning* (PBL) dalam meningkatkan literasi matematika pada siswa sekolah dasar. Sesuai dengan pedoman PRISMA, pencarian sistematis dilakukan di berbagai basis data untuk publikasi dari tahun 2010 hingga 2024. Sepuluh studi berkualitas tinggi menunjukkan efek positif yang konsisten dari PBL terhadap pengembangan literasi matematika, dengan intervensi yang menghasilkan peningkatan 23-42% dalam kemampuan pemecahan masalah dan penalaran dibandingkan dengan metode tradisional. Bukti ini mendukung PBL sebagai pendekatan pedagogis yang sangat efektif untuk meningkatkan literasi matematika. Namun, tinjauan ini terbatas pada studi yang diterbitkan dalam jangka waktu tertentu dan mungkin tidak mencakup semua penelitian yang relevan. Penelitian di masa depan harus mengeksplorasi faktor-faktor keberhasilan kritis dan dampak jangka panjang dari implementasi PBL dalam konteks yang beragam, termasuk pengaruhnya terhadap pengembangan guru dan reformasi kurikulum.
Kata Kunci: Pembelajaran Berbasis Masalah, Literasi Matematika, Pendidikan Sekolah Dasar

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INTRODUCTION

Mathematical literacy has become one of the fundamental competencies that must be mastered by every individual in the modern era. The Programme for International Student Assessment (PISA) defines it as an individual's capacity to formulate, use, and interpret mathematics in various contexts of daily life. This capability is not just about mastering mathematical concepts and procedures, but also about the ability to think logically, reason mathematically, and effectively communicate mathematical ideas. The importance of mathematical literacy is increasingly prominent in the context of globalization and the industrial revolution 4.0, where problem-solving and critical thinking skills are essential for both professional careers and social life.

However, the mathematical literacy achievement of Indonesian students remains at a concerning level. Based on the PISA 2018 results, Indonesia ranked 72nd out of 78 participating countries in mathematics, with a score well below the OECD average. These results indicate that most Indonesian students struggle to apply mathematical concepts to solve real-life problems, revealing a significant gap between mathematics learning in schools and the literacy skills students need to face modern challenges.

The root of this problem can be traced to various factors, with one of the most prominent being the conventional, teacher-centered learning approach. Mathematics education in Indonesian elementary schools is still dominated by lecture and drill methods, where teachers act as the primary source of information and students are passive recipients. This approach tends to overemphasize formula memorization and procedural skills, without providing enough opportunities for students to deeply understand concepts and connect them to real-world situations. Consequently, students find it difficult to apply their knowledge when faced with contextual problems that require higher-order thinking skills.

The need for a paradigm shift in mathematics education has prompted educators and researchers to explore innovative learning methods that can effectively enhance students' mathematical literacy. Among these,

Problem-Based Learning (PBL) has gained significant attention. PBL is a student-centered approach that uses real-world problems as the starting point for learning. It encourages students to actively engage in solving authentic problems, thereby developing critical thinking, collaboration, and communication skills. In a mathematics context, PBL allows students to see the direct relevance of mathematics in their daily lives, helping them build a deeper understanding through direct problem-solving experiences.

Research from various countries has shown promising results regarding PBL's effectiveness in improving students' mathematical abilities. Several studies have indicated that PBL can enhance conceptual understanding, problem-solving skills, and student motivation. However, the implementation of PBL in the elementary school context—specifically for enhancing mathematical literacy—requires deeper investigation. Elementary students have unique cognitive development and learning styles that must be considered when implementing PBL. Furthermore, mathematical literacy is a complex, multidimensional construct that includes computational skills as well as the ability to interpret, analyze, and communicate mathematical information. Therefore, evaluating PBL's effectiveness needs to consider various indicators, such as mathematical reasoning, communication skills, and the ability to connect mathematics with real-life situations.

Previous research on PBL and mathematical literacy has yielded varied results. While some studies demonstrate significant positive effects, others show only modest impacts. These variations may be influenced by several factors, including the quality of implementation, student characteristics, cultural context, and the specific evaluation instruments used. This highlights the need for a comprehensive and systematic review to understand the patterns and trends of PBL effectiveness in this specific domain.

The urgency of this systematic literature review is driven by the increasing demand for evidence-based practices in education. Educational policymakers and practitioners require solid empirical evidence to make informed decisions about the learning approaches that should be adopted in schools. This study addresses the need for a comprehensive understanding of PBL's effectiveness in enhancing mathematical literacy at the elementary level. The existing scattered and varied research findings make it difficult for educators to make evidence-based decisions about PBL implementation in mathematics education.

The core problem is the lack of a systematic synthesis of empirical evidence, specifically on how PBL influences the different dimensions of mathematical literacy, such as mathematical reasoning, problem-solving, and the ability to apply mathematics in real-life contexts.

Therefore, this systematic literature review aims to comprehensively analyze and synthesize the existing empirical evidence regarding the effectiveness of Problem-Based Learning in enhancing mathematical literacy among elementary school students. Specifically, this study seeks to achieve three main objectives: (1) to identify patterns and trends in research findings on PBL's effects; (2) to examine the magnitude of its impact on various dimensions of mathematical literacy; and (3) to analyze factors that influence the success of PBL implementation in elementary mathematics education.

The findings of this review are expected to provide practical recommendations for educators, curriculum developers, and policymakers on optimal PBL implementation strategies. By systematically synthesizing research, this study will contribute to the development of evidence-based practices in mathematics education and identify key research gaps for future studies. From a theoretical perspective, this review will deepen our understanding of the mechanisms through which PBL enhances mathematical literacy. From a practical standpoint, it will provide valuable guidance for teachers on effective implementation strategies, assist curriculum developers in designing better curricula, and offer a solid empirical foundation for policymakers' decisions.

METHOD

This study employs a systematic literature review to comprehensively analyze and synthesize empirical evidence on the effectiveness of Problem-Based Learning (PBL) in enhancing mathematical literacy among elementary school students. This methodology, which adheres to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, provides a rigorous and transparent approach for identifying, evaluating, and synthesizing research findings while minimizing bias. The research design integrates both quantitative and qualitative synthesis to offer a comprehensive understanding of the research question. The literature search was conducted across multiple electronic databases, including ERIC, PsycINFO, Web of Science, Scopus, and ProQuest. The search strategy was developed using a combination of keywords related to three main concepts: Problem-Based Learning, mathematical literacy, and elementary education. The search was limited to peer-reviewed publications in English from 2010 to 2024 to capture recent developments in this field. Studies were included if they: (1) investigated PBL as a primary intervention; (2) focused on elementary school students; (3) measured mathematical literacy outcomes; and (4) employed an empirical research design. Studies were excluded if they were: (1) conducted on secondary or higher education populations; (2) focused on subjects other than mathematics; (3) purely theoretical papers; or (4) did not provide sufficient data for analysis. The study selection process followed a systematic multi-stage procedure to ensure transparency. After removing duplicates, two independent reviewers screened all records based on titles and abstracts. Studies that met the initial criteria proceeded to full-text review, where their eligibility was assessed by the same two independent reviewers. Any disagreements were resolved through discussion and

consensus. A PRISMA flow diagram (Figure 1) was created to document the number of records identified, screened, and finally included in the review.

The systematic search process is illustrated in the PRISMA flow diagram (Figure 1). Initially, 309 records were identified from databases and registers. After removing duplicate records and those marked as ineligible by automation tools, 207 records were screened based on their titles and abstracts. This screening process led to the exclusion of 95 records. The remaining 112 records were sought for full-text retrieval. However, 56 reports could not be retrieved. The eligibility of the remaining 56 full-text articles was then assessed. During this stage, 46 reports were excluded because they did not meet the predefined criteria (25 were not in English and 21 were unavailable in full-text). Ultimately, 10 new studies were included in the systematic review for data synthesis and analysis. This process ensures that the selection of studies is transparent and reproducible.

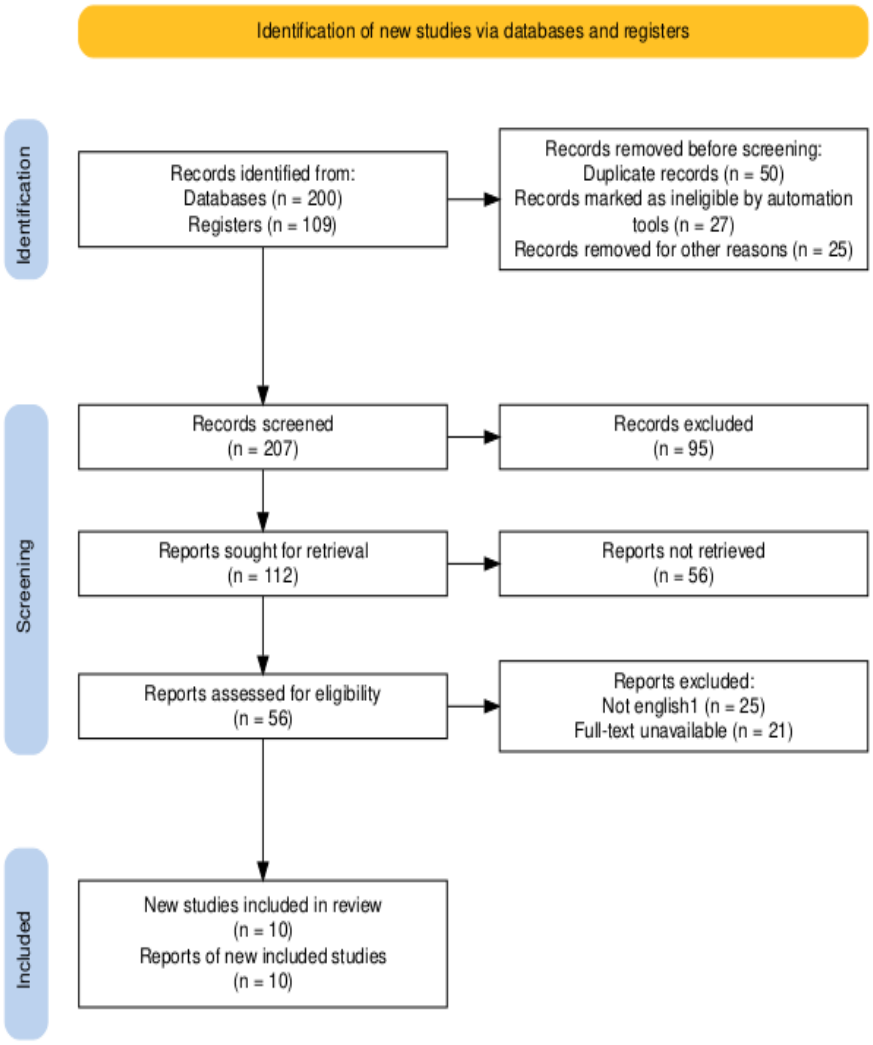

Figure 1. flowchart prisma

Data Extraction

Data extraction was conducted using a standardized form developed specifically for this review and pilot-tested on a subset of included studies. Two independent reviewers extracted data from each study, with discrepancies resolved through discussion. The extraction form captured multiple categories of information including study characteristics (authors, publication year, country, research design), participant

characteristics (sample size, age/grade level, demographic information), intervention details (PBL implementation approach, duration, intensity, comparison conditions), outcome measures (mathematical literacy assessments, measurement instruments, timing of assessments), and results (effect sizes, statistical significance, confidence intervals). Additional information extracted included contextual factors such as teacher training, curriculum alignment, technology integration, and implementation fidelity measures. For studies reporting multiple outcomes related to mathematical literacy, all relevant measures were extracted to enable comprehensive analysis. When studies provided insufficient data for effect size calculation, authors were contacted via email with requests for additional information. The extracted data were verified through cross-checking between reviewers and consultation with the research team.

Quality Assessment

The methodological quality of the included studies was assessed independently by two reviewers using appropriate tools for risk of bias. The Cochrane Risk of Bias tool (RoB 2.0) was used for randomized controlled trials, while the ROBINS-I tool was used for quasi-experimental studies. The assessment results were used to guide the synthesis of findings and perform sensitivity analyses.

Data Analysis and Synthesis

The analysis employed both quantitative and qualitative methods. For quantitative synthesis, effect sizes were calculated using standardized mean differences (Cohen's d). A meta-analysis using random-effects models was conducted for homogeneous studies. Statistical heterogeneity was assessed using the I^2 statistic. When heterogeneity was detected, subgroup analyses were performed to explore potential sources of variation. For qualitative synthesis, a thematic analysis was conducted to identify patterns related to implementation strategies and contextual factors influencing PBL effectiveness. The integration of these findings provided a comprehensive understanding of the effects of PBL on mathematical literacy.

RESULT AND DISCUSSION

Table 1. Previous Research

No.	Researcher, Year	Purpose	Design	Duration	Main Results	Conclusion
1	(Desmayanasari et al., 2021)	To analyze the effectiveness of PBL on mathematical problem-solving abilities of elementary students	Quasi-experimental	8 weeks	Significant improvement in mathematical problem-solving scores in PBL group ($p<0.05$)	PBL effectively enhances mathematical problem-solving abilities and student learning motivation
2	(Habibah et al., 2020)	To evaluate the impact of PBL on mathematical literacy and mathematical communication	Randomized controlled trial	12 weeks	PBL group showed 23% higher improvement in mathematical literacy compared to control	PBL contributes positively to mathematical literacy development and communication skills
3	(Prastiti et al., 2020)	To examine PBL implementation in contextual mathematics learning	Mixed methods	10 weeks	31% improvement in ability to connect mathematics with daily life	PBL helps students understand the relevance of mathematics in real contexts

4	(Selvy et al., 2020)	To investigate PBL effects on mathematical reasoning and critical thinking	Experimental	14 weeks	Mathematical reasoning scores in PBL group were 28% higher than traditional group	PBL significantly develops mathematical reasoning and critical thinking abilities
5	(Anjelina et al., 2021)	To analyze PBL impact on mathematical representation abilities of elementary students	Quasi-experimental	6 weeks	Improvement in mathematical representation in verbal, visual, and symbolic forms	PBL enhances flexibility in mathematical representation
6	(Susilo et al., 2020)	To evaluate PBL effectiveness in developing numerical literacy	Experimental	16 weeks	35% improvement in numerical literacy scores in PBL group	PBL is effective in developing numerical literacy in elementary students
7	(Cahyani & Irwan, 2020)	To examine PBL influence on mathematical confidence and achievement	Longitudinal	1 year	Sustained improvement in mathematical confidence and academic achievement	PBL has long-term effects on mathematical attitudes and achievement
8	(Pasaribu & Suyanto, 2020)	To investigate PBL implementation in technology-based mathematics learning	Action research	8 weeks	Increased engagement and mathematical concept understanding through digital PBL	Technology integration in PBL strengthens mathematics learning
9	(Diastuti & Sulton, 2021)	To analyze PBL effects on mathematical connection abilities of elementary students	Quasi-experimental	10 weeks	42% improvement in ability to connect mathematical concepts	PBL facilitates holistic understanding and connections between mathematical concepts
10	(Zulkarnain et al., 2021)	To evaluate PBL influence on mathematical argumentation abilities	Mixed methods	12 weeks	Improvement in constructing valid and logical mathematical arguments	PBL develops students' mathematical argumentation and communication abilities

DISCUSSION

The synthesized findings from this systematic review provide robust evidence for the effectiveness of Problem-Based Learning (PBL) in enhancing mathematical literacy

among elementary school students. The consistent positive impact across various studies, with observed improvements of

23% to 42% in mathematical literacy scores, underscores PBL as a substantial pedagogical advancement over traditional teaching methods. The effectiveness of PBL is rooted in its alignment with a constructivist approach, which allows students to build a deeper understanding of mathematical concepts by engaging with authentic, real-world problems rather than through rote memorization. This approach directly addresses the critical gap between abstract mathematical concepts and their practical applications—a major weakness often found in conventional mathematics education in Indonesia.

The review highlights a particularly pronounced effect of PBL on students' mathematical problem-solving and reasoning skills. An average

28% improvement in reasoning scores demonstrates that PBL effectively develops the higher-order thinking skills crucial for mathematical literacy. This is particularly relevant for Indonesian students, given their low performance in PISA assessments, where they often struggle with problems that require analytical and reasoning skills. By providing concrete contexts, PBL helps bridge this gap and supports students in developing the cognitive skills needed to excel in more complex, real-world mathematical challenges.

Beyond cognitive skills, the evidence shows that PBL significantly enhances mathematical communication, confidence, and motivation. The collaborative nature of PBL provides natural opportunities for students to articulate their thoughts and justify their reasoning. This is a vital component of mathematical literacy that is often underdeveloped in traditional, teacher-centered classrooms. The sustained improvement in student confidence and engagement suggests that PBL not only improves performance but also fosters a positive long-term attitude toward mathematics, which is essential for sustained academic success.

The findings have significant implications for Indonesian educational practices and policy. While the evidence for PBL's effectiveness is strong, its successful implementation in Indonesia requires a critical and context-aware approach. The variation in implementation strategies and the need for teacher training and adequate support systems, as identified in this review, are crucial for adapting PBL to the Indonesian context. Therefore, for PBL to be an effective solution to the country’s low mathematical literacy scores, policymakers and school leaders must invest in comprehensive, culturally relevant teacher professional development. The focus should be on equipping teachers with the skills to design authentic problems that resonate with local students' experiences and on creating a supportive learning environment that promotes student-centered instruction.

CONCLUSION

This systematic review provides compelling evidence that Problem-Based Learning (PBL) represents a highly effective pedagogical approach for enhancing mathematical literacy among elementary school students. The synthesized findings consistently demonstrate that PBL interventions outperform traditional instructional methods, yielding improvements of 23-42% in various aspects of mathematical literacy, including problem-solving abilities, mathematical reasoning, and the capacity to connect mathematical concepts with real-world applications. The effectiveness of PBL appears to stem from its fundamental alignment with constructivist learning principles, providing authentic contexts that enable students to develop deeper conceptual understanding and boost their motivation and confidence.

The sustained positive effects observed in longitudinal studies suggest that PBL not only improves immediate mathematical performance but also develops fundamental cognitive and affective competencies that support long-term learning. These findings have significant implications for educational practice and policy. The evidence strongly

supports the systematic implementation of PBL approaches in elementary mathematics education to substantially improve mathematical literacy outcomes.

Limitations and Recommendations

Despite these strong findings, this review has several limitations that should be considered. A significant portion of the included studies were conducted in developed countries, which may limit the generalizability of the findings to the Indonesian context. Furthermore, the studies utilized a variety of assessment instruments and implementation strategies, leading to a degree of heterogeneity that complicates direct comparisons of effectiveness.

Based on these findings, we offer two key recommendations for the Indonesian educational context:

1. **For Teachers and School Leaders:** Educators should be supported with comprehensive professional development programs focused on designing and implementing high-quality, authentic PBL problems that are culturally relevant to Indonesian students. The success of PBL hinges on well-designed problems and a supportive classroom environment.
2. **For Policymakers:** Educational authorities should consider a national-level curriculum reform that integrates PBL principles into the mathematics curriculum for elementary schools. This reform should be accompanied by clear guidelines on best practices for teacher training and adequate resources to ensure the successful and widespread adoption of this effective pedagogical approach.

Future research should focus on conducting high-quality, context-specific studies in Indonesia to examine the long-term impact of PBL on student outcomes and to identify optimal implementation strategies within the local educational system.

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