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Effectiveness of Project-Based Learning in Enhancing Mathematical Reasoning and Creativity: A Systematic Review

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Abstract
This systematic review incorporates empirical evidence about the effectiveness of Project-Based Learning (PBL) in developing the mathematical reasoning and creativity of students. Following PRISMA 2020 guidelines, twenty peer-reviewed empirical studies conducted on various educational levels and in different international contexts were identified and analyzed. Overall, findings across the included studies are largely in agreement in finding that PBL is related to positive effects on mathematical reasoning and creative thinking compared with more conventional teaching approaches, especially if projects are authentic and interdisciplinary and are supported with structured collaboration. PBL models combined with STEM learning, computational thinking or guided peer interaction (e.g. Think-Pair-Share) tend to report better outcomes. Greater flexibility, fluency, and originality in problem solving and deeper conceptual understanding and reflective reasoning are often exhibited by learners in real-world project tasks. Evidence from a meta-analytic synthesis also indicates a large positive effect of STEM-oriented PBL on creativity also suggesting that interdisciplinary PBL design may enhance creative outcomes. However, the generalizability of results is limited because of the short intervention periods, small sample sizes and the lack of consistency in assessment tools. The review concludes that well-conceived PBL - the provision of a solid foundation in inquiry, authenticity, and formative feedback - can be used to support the development of mathematical reasoning and creativity, while future research should focus on longitudinal and multi-site studies to consider the issue of sustainability in different contexts.

Keywords: Mathematical reasoning, creativity, STEM education, PRISMA systematic review

Introduction

Mathematics is a cornerstone of education in today's world that contributes to individual cognitive development along with a wider social and economic development. Strong mathematical competence is closely attributed to technological innovation, productivity, and national development. Despite the importance of mathematics, for some reason, mathematics teaching has tended to be criticized for an over focus on procedural fluency, while there has been limited attention given to conceptual understanding, reasoning, and creative problem solving. Such approaches may limit the ability of learners to use mathematical knowledge in a flexible and meaningful way in a real-world context.

In response to these concerns, Project-Based Learning (PBL) has emerged as a learner-centered instructional approach based upon constructivist principles. PBL involves students in sustained inquiry, authentic problem solving and collaborative knowledge construction and develops the higher-order thinking skills. The rising importance of it has been closely tied to the education requirements in the twenty-first century, especially the attainment of critical thinking, creativity, collaboration, and communication skills (Ukobizaba et al., 2025). Within the field of mathematics education, PBL offers possibilities for learners to apply abstract concepts to practical situations and encourage logical reasoning, reflection and conceptual understanding (Ndiung & Menggo, 2024). Furthermore, the integration of PBL in the context of STEM education has proven especially promising in the achievement of mathematical reasoning and creativity in the context of interdisciplinary and context-rich tasks (Bicer et al., 2025; Kwon & Lee, 2025).

For the sake of conceptual clarity, this review defines mathematical reasoning as the capacity to analyze relationships, build logical arguments, make justifications, and make connections between mathematical ideas in different representations and in different situations. Mathematical creativity, in contrast, refers to learners' ability to create original, flexible and appropriate solution strategies (and often is reflected in fluency, flexibility, and originality in mathematical problem solving). These constructs are theoretically supported by the theory of constructivism in learning and the emphasis on active knowledge construction through inquiry and interaction, problem-solving theory and the importance of learning through involvement with complex and meaningful tasks, and creativity theory and the creative thinking perspectives of divergent thinking in particular, which emphasizes the generation of multiple ways to solve problems.

Although empirical interest in PBL with respect to mathematics education has increased substantially, its implementation and its claimed effectiveness remain uneven. Variations across to different regions and education levels, teaching methods and teacher preparation, which contribute to mixed outcomes. For example, research in Indonesia and Malaysia has often achieved high gains in mathematical reasoning and creativity (Nasution et al., 2025; Hanafi et al., 2025), while studies in other settings have shown smaller or inconsistent effects, which are often explained by short intervention times, insufficient scaffolding or resource constraints (Wati & Wutsqa, 2024; Himmi et al., 2025). In addition, the way that reasoning and creativity are measured differs considerably between studies that limits the comparability between studies (Marfu'ah et al., 2023; Telegina et al., 2019).

More significantly, the available literature shows a number of critical gaps. First, most empirical research focuses on mathematical reasoning and creativity separately and relatively few studies investigate their joint development in PBL environments. Second, large methodological variations are present in terms of intervention duration, project design, and assessment tools rendering the strength of the cumulative evidence weak (Li & Tu, 2024; Rahayu & Putri, 2021). Third, the influence of contextual factors, such as resource availability, teacher expertise and limitations of curriculum, has often been noted but not systematically collated thus making it difficult to determine the conditions under which PBL works best.

Although recent secondary studies and bibliometric reviews have been conducted on the trends in PBL research (Hanafi et al., 2025; Ukobizaba et al., 2025), a systematic review that synthesizes empirical evidence on the co-development of mathematical reasoning and creativity from a wide range of educational context are limited in scope. In addition, limited reviews use a strict PRISMA 2020 framework for their research and focus on the latest empirical evidence. Addressing this gap is important for clarifying the effectiveness of PBL as a whole, identifying important moderating factors, and evidence-based instructional/curricular decisions.

Accordingly, this systematic review has a unique contribution in that it (a) considers mathematical reasoning and creativity within the context of PBL in the same review, (b) synthesizes the current state of empirical evidence across different educational levels and across different global contexts (using PRISMA 2020 guidelines), and (c) identifies the instructional, contextual, and methodological factors that affect reported outcomes.

The main objectives of this research are as follows:

1. To synthesize recent empirical evidence on the effectiveness of PBL in enhancing mathematical reasoning and creativity across educational levels and contexts
2. To identify key instructional, contextual, and assessment-related factors influencing the effectiveness of PBL in mathematics education
3. To examine research trends and methodological gaps that inform future research directions and instructional practice

This research has been conducted in light of the research questions mentioned below.

1. What is the overall impact of PBL on students' mathematical reasoning and creative thinking as reported in peer-reviewed empirical studies?
2. Which PBL designs or integration models (e.g., STEM-integrated PBL, Think–Pair–Share-supported PBL, and modified PBL) are associated with stronger learning outcomes?
3. Which contextual and methodological factors (e.g., educational level, intervention duration, assessment approach) contribute to variation in reported outcomes?
4. What research and practical gaps remain for future large-scale or longitudinal investigations?

Methods and Procedures

This systematic review was carried out following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) guidelines in order to ensure transparency, methodological rigor, and replicability. The review process was carried out in four consecutive stages - identification, screening, eligibility, and inclusion. A review protocol was drafted in advance to define the scope of the review, search strategy, inclusion and exclusion criteria, data extraction procedures, and quality appraisal approach. Establishment of this protocol before studies were selected helped to minimize selection bias and increase the reliability of the review. While the procedures were guided by PRISMA 2020 standards, minor modifications were made to account for the methodological diversity that is typical of educational research.

A thorough search of the literature was performed in order to identify relevant empirical studies published between 2016 and 2025. Searches were conducted in established academic databases including Scopus, ERIC and Springer-Link to ensure coverage of high-quality and peer-reviewed literature. In addition, Google Scholar and Research Gate were employed as supplementary search platforms rather than formal databases in order to find additional open-access articles and early view publications that might not have been indexed in the primary databases. In the Google Scholar database, search results were ordered by relevance, and the top 200 records were screened, in line with the practice of systematic reviews. Research Gate was mainly used to obtain full-text versions of already identified studies and to find additional peer-reviewed articles via authors. Manual searches of reference lists of key empirical studies and recent reviews (e.g. Ukobizaba et al., 2025; Hanafi et al., 2025) were also performed to complete the search.

The search strategy was based on fully-bracketed Boolean operators to allow reproducibility. Searches were performed in title, abstract and keywords, if that functionality is available within the database. The final search string was: (“Project-based learning” OR “PBL” OR “STEM-PBL”) AND (“mathematical reasoning” OR “reasoning ability”) AND (“creativity” OR “creative thinking” OR “innovation”) AND (“mathematics education” OR “mathematics learning” OR “math learning).

Studies were considered if they satisfied the following criteria: peer-reviewed journal article, published between 2016 and 2025, empirical research design including quantitative, qualitative, mixed-methods, Project-Based Learning or a modified PBL model, mathematics education, measured outcomes related to mathematical reasoning, creativity or both, participants included in the study were from a primary, secondary or tertiary education, the study was published in English. Studies were excluded if non-empirical or solely conceptual studies, if they were STEM education instead of specifically about mathematics, if the source was non-peer reviewed sources such as institutional reports, publication theses, or other sources (e.g., not a peer-reviewed article), but were full texts (no full text was accessible), incomplete, or inaccessible.

The first search produced 412 records. A total of 350 studies were screened for inclusion based on the titles and abstracts after the removal of 62 duplicates. Of these, 290 records were excluded because they were not relevant to PBL, mathematics education or the target outcome variables. The remaining 60 full-text articles were checked for eligibility and after methodological verification and relevance checks, 20 studies met all the inclusion criteria and were included in the final synthesis. The process of selecting the studies is summarized in a PRISMA flow diagram (Figure 1).

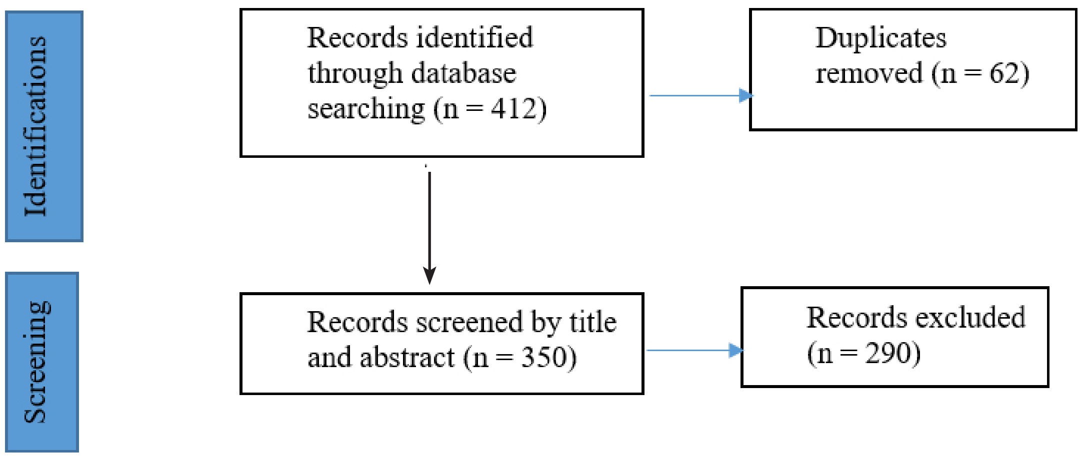
In order to reinforce the reliability of review results, a quality appraisal and risk of bias was performed for all included studies. Quantitative and mixed-methods studies were assessed against criteria of clarity of research design, adequacy of sample size, validity/ reliability of measuring instruments, clarity of intervention procedures, and appropriateness of analytical methods. Qualitative studies were evaluated on the following aspects: clarity of research aim, rigor of data collection, transparency of analysis, and credibility of interpretation. Based on these criteria, studies were classified as high, moderate, or low methodological quality. Studies that were judged as lower quality research were also retained but interpreted cautiously when synthesizing the data to avoid overgeneralization.

For the included studies, relevant data were systematically extracted and recorded in a comparative matrix addressing the author(s) and year of publication, country and grade, sample characteristics, research design, description of the PBL intervention (e.g., type and duration), measurement approaches for mathematical reasoning and creativity, key findings, and reported limitations. A narrative thematic synthesis was then used to combine findings across studies that used homogeneous designs. The synthesis focused on identifying recurring patterns related to the development of mathematical reasoning, enhancement of creativity, and effectiveness of integrated or hybrid PBL models and contextual and implementation-related challenges.

The general procedure of the selection was based on the PRISMA 2020 (Figure 1)

Figure 1

PRISMA Flow Diagram



For the 20 included studies, data were systematically extracted and organized into a comparative table (Table 1), and key information such as the author(s) and year of publication, country or region and educational level, sample size and characteristics of participants, research design and methodology, description of the project-based learning (PBL) intervention (type, duration and activities included), methods used to measure mathematical reasoning and creativity, and key findings and reported limitations of each study were included. A narrative thematic synthesis was then carried out to bring together findings across studies with heterogeneous designs. Theme development occurred in an iterative coding process, whereby the key findings and reported outcomes were initially coded inductively to identify recurring concepts in relation to reasoning and creativity, instructional design, and conditions in the context. These initial codes were then refined and grouped into larger themes based on constant comparison between studies based on the review objectives. To contribute to the analytical rigor, results of findings were triangulated across different study designs (quantitative, qualitative and mixed-methods), and educational contexts, so that themes represented convergent evidence rather than single study results. This process led to four main themes, namely: (1) improvement in mathematical reasoning through PBL, (2) fostering creativity and innovative thinking, (3) effectiveness of STEM in and modified PBL models, and (4) problems of context and implementation.

Results

This section presents the results of the systematic review according to the 20 studies that met the inclusion criteria. The various studies included were based in different geographical settings and were carried out in Indonesia, Malaysia, China, the United States, Pakistan, Nigeria, Russia, Rwanda and Hong Kong. A variety of research designs have been used among the reviewed studies: experimental, quasi-experimental, mixed-methods, descriptive, bibliometric, and meta-analytic research designs.

The results are presented in two parts: (a) a descriptive overview of the included studies and (b) a summary of reported outcomes that are related to mathematical reasoning and creativity in the context of PBL.

The results are organized into two sections: a descriptive overview of the included studies and a thematic synthesis of their findings.

Descriptive Overview of Included Studies

Table 1 provides an overview of the twenty peer-reviewed studies that were included in this review. The studies are a mix of classroom-based empirical studies, mixed-methods studies and secondary studies (bibliometric and meta-analytic reviews). Most of the studies were carried out at the level of secondary education, followed by primary education, tertiary education, and teacher education. Indonesia was the region with the highest number of empirical studies, but other regions were also covered to a less extent.

Table 1

Descriptive Overview of Included Studies

Author(s) & Year	Country / Level	Design	Focus	Main Findings
Ukobizaba et al. (2025)	Rwanda, Secondary	Review	PBL in Math & Science	Reported positive outcomes related to creativity, reasoning, and collaboration
Prayekti (2025)	Indonesia, Middle School	Quasi-experimental	Mathematical reasoning	Reported higher reasoning scores in the PBL group
Hanafi et al. (2025)	Malaysia, Global	Bibliometric review	PBL trends	Identified growth in PBL research, with reasoning and creativity as dominant themes

Marfu'ah et al. (2023)	Indonesia, High School	Experimental	Reasoning ability	Reported improvement in reasoning with PBL and performance assessment
Ndiung & Menggo (2024)	Indonesia, Primary	Experimental	Reasoning and creativity	Reported gains in reasoning and problem-solving skills
Li & Tu (2024)	China, University	Experimental (PBL + TPS)	Creativity	Reported increased creative fluency and flexibility
Kwon & Lee (2025)	South Korea	Meta-analysis	Creativity	Reported a large effect size for STEM-integrated PBL on creativity
Telegina et al. (2019)	Russia, Secondary	Descriptive	PBL practice	Reported improvements in conceptual understanding and reasoning
Nasution et al. (2025)	Indonesia, Secondary	Modified PBL	Creativity	Reported higher creative thinking scores
Ferdiansyah et al. (2025)	Indonesia, Secondary	Experimental	STEM-PBL	Reported gains in creative reasoning and innovation
Rehman et al. (2024)	Pakistan, Secondary	Mixed-methods	21st-century skills	Reported improvements in engagement, collaboration, and reasoning
Johnson (2021)	USA, Special Education	Action research	Applied reasoning	Reported positive outcomes for learners with special needs
Ummah et al. (2019)	Indonesia, Junior High	Quasi-experimental	Creativity	Reported increased creativity and persistence
Rahayu & Putri (2021)	Indonesia, Junior High	Case study	Applied mathematics	Reported improved reasoning and collaboration

Himmi et al. (2025)	Global	Review	PBL practices	Reported positive outcomes with implementation variability
Cahyadi et al. (2024)	Indonesia, University	Evaluation	Creativity and innovation	Reported innovation gains with strong scaffolding
Wati & Wutsqa (2024)	Indonesia, Secondary	Comparative	Reasoning and self-regulation	Reported comparable reasoning outcomes across instructional models
Bicer et al. (2025)	USA, Pre-service teachers	Mixed-methods	STEM-PBL	Reported enhanced mathematical creativity
Han et al. (2016)	USA, Secondary	Experimental	Critical reasoning	Reported improved reasoning and critical thinking
Ji & Wong (2025)	Hong Kong, Primary	Experimental	Computational thinking	Reported gains in creativity

Across the included studies, outcomes relating to mathematical reasoning were often measured using achievement tests or other assessments of reasoning or performance-based tasks. The majority of empirical studies indicated that students exposed to PBL post-intervention reasoning scores were higher than in comparison or control groups.

Outcomes associated with mathematical creativity were measured using creativity tests, rubric-based assessment of student products, or measures such as fluency, flexibility and originality. Several studies reported increased levels of creativity-related scores and/or enhanced creative performance as a result of PBL interventions, especially in studies involving either STEM-oriented or modified PBL designs.

Studies in which integrated or hybrid PBL models were implemented, including STEM-integrated PBL, Think-Pair-Share-supported PBL, and computational thinking-oriented PBL, often had positive results in both measures of reasoning and creativity. A meta-analytic study found a large aggregated effect size for outcomes of creativity related to STEM integrated PBL interventions.

Despite these reported outcomes, there were also a number of studies which reported on methodological limitations, such as brief intervention durations, small sample sizes and variability in assessment instruments. The geographical distribution of studies showed a strong focus of studies done in the context of Southeast Asia, with lesser studies from other regions.

Discussion

This section is used to interpret the findings of the systematic review and discuss the implications of the findings in terms of the theory, pedagogy, and research. Across the 20 peer-reviewed studies the evidence supports mathematical reasoning and creativity improvements for PBL, especially if it is implemented using authentic tasks, collaborative learning and proper instructional scaffolding. The summation of findings resulted in 5 interrelated themes supporting understanding of how and under what conditions PBL supports these learning outcomes.

Enhancement of Mathematical Reasoning

The reviewed studies indicate that PBL facilitates the development of mathematical reasoning by drawing upon the learners in higher-order problem-solving processes, which call for justification, explanation, and reflection. Empirical evidence, derived from experimental and quasi-experimental studies, has shown that students who have been exposed to PBL evidence enhanced analytical reasoning and argumentation capabilities as compared to students who have been taught using conventional instructional strategies (Prayekti, 2025; Marfu'ah et al., 2023). Contextualized project tasks, which include real-life or community-based problems, do seem to support connections between conceptual understanding and procedural knowledge (Rahayu & Putri, 2021; Ndiung & Menggo, 2024). These results are consistent with the knowledge construction theory of constructivism, which stresses inquiry, interaction, and reflection as the key elements in the learning process. However, there is also evidence that the gains in reasoning require the proper scaffolding and learner self-regulation as unguided projects may focus on completing the task rather than conceptual reasoning (Wati & Wutsqa, 2024).

Promotion of Creativity and Innovative Thinking

Creativity, one of the competencies of twenty-first century education, is always reported as one positive result of PBL implementation. A meta-analytic conducted study reported a high effect of STEM-integrated PBL on creativity (ES = 3.88), suggesting the potential strength of interdisciplinary project designs for the facilitation of creative thinking. Further empirical research has found enhancements in creative fluency, flexibility, and originality in the collaborative and design-based project work (Li & Tu, 2024; Nasution et al., 2025). Project tasks which entail manipulative construction or interdisciplinary product design are also linked to greater persistence and divergent thinking (Ummah et al., 2019; Ferdiansyah et al., 2025). Collectively, these findings suggest that creativity in PBL contexts is supported by learner autonomy, authenticity of tasks, and opportunities for reflection, although an appropriate balance between structure and exploration is essential (Cahyadi et al., 2024).

Integration of STEM and Hybrid PBL Models

The synthesis leads us to the fact that the results of PBL are often supported by an integration with other complementary pedagogies such as STEM integration or computational thinking, or even well-structured peer interaction (such as Think-Pair-Share). Studies that employ hybrid models are reporting improvements in the accuracy of reasoning and creativity in products from interdisciplinary problem solving and peer-assisted reflection (Bicer et al., 2025; Han et al., 2016; Ji & Wong, 2025). There has also been evidence indicating that supports the deeper reflective reasoning, and the interdisciplinary integration supports the flexible application of mathematical knowledge (Li & Tu, 2024; Kwon & Lee, 2025). The reason is that these representational patterns are consistent with cognitive load and knowledge transfer perspectives that really emphasize the value of multiple representations and contextualized learning. Nevertheless as the hybrid PBL models are successfully implemented, they appear to necessitate advanced teacher expertise, carefully planned pedagogy, and continuous professional development (Himmi et al., 2025).

Mediators, Moderators, and Pedagogical Mechanisms

The effectiveness of PBL is mediated by a number of instructional and learner-related factors. Teacher scaffolding is revealed to be an important mediator to support the development of reasoning with guided inquiry and structured feedback (Prayekti, 2025). Creativity-related outcomes are influenced by learner autonomy and motivation, which allows them to engage in flexible exploration and be original in the problem-solving process (Li & Tu, 2024; Nasution et al., 2025). Longer intervention intervals and regular formative feedback have added strength to the evident learning increases while performance-based assessment in response to project goals seems to promote cognitive and creative growth (Marfu'tah et al., 2023; Ferdiansyah et al., 2025). Overall, the evidence seems to indicate that the effectiveness of PBL is dependent on an interaction of cognitive, motivational and contextual factors, rather than any particular instructional component.

Contextual Challenges and Implementation Issues

Despite generally positive findings, the review demonstrates the existence of a number of difficulties that affect the consistency and generalization of findings from PBL: Variability in terms of teacher preparation, resources availability and assessment practices add to uneven implementation especially in resource constrained settings (Ukobizaba et al., 2025; Himmi et al., 2025). Weak scaffolding, and/or poorly specified assessment rubrics have been found to limit creative development (Cahyadi et al., 2024) and such infrastructures as short intervention times reduce the reliability of observed improvements in reasoning (Wati & Wutsqa, 2024). In addition, special educational needs learners require specific support to be able to benefit from PBL approaches (Johnson, 2021). The aggregation of studies in the Southeast Asian contexts further limits the cross-cultural generalization and hence wide geographical representation is needed (Hanafi et al., 2025). Collectively these limitations suggest the importance of research designs that are more comprehensive (large scale and longitudinal) and standardized in nature of assessment.

Overall, the results are consistent with the theories of constructivism and experiential learning that show that inquiry-based projects can include the cognitive and affective aspects of learning mathematics. From a pedagogical point of view PBL should be integrated into curricula in the form of carefully designed projects, continuous formative assessments and long-term professional development for teachers. At the policy level, the support of competency-based and creativity-oriented curriculum require institutional support in terms of resources, teacher training and interdisciplinary collaboration. Future research focuses more on multi-site longitudinal research, better measurement of reasoning and creativity, as well as more attention to educational contexts that are underrepresented, e.g. research on digital and hybrid learning environments. Together, these findings make PBL an interesting pedagogical approach to encourage both analytical reasoning and creative competence in mathematics education.

Conclusion

This is a systematic review of the empirical evidence from 20 peer-reviewed studies that used PBL to explore the effectiveness of this approach in mathematics education in relation to the enhancement of mathematical reasoning and creativity. Following the methodology of the PRISMA 2020 framework, the findings of the review were combined regardless of the different research designs, educational levels and geographical contexts. The reviewed evidence suggests that the PBL approach is consistently linked to improvements in both mathematical reasoning and creativity, especially if learning activities are authentic, inquiry-based and supported by structured collaboration and scaffolding.

Four important conclusions can be drawn from this review. First, PBL supports the development of mathematical reasoning because it engages learners in complex and real-world tasks that require the explanation, justification, logical structuring of ideas. Second, PBL promotes mathematical creativity through the encouragement of multiple ways of solving a problem, originality, and flexible thinking, proving that creativity and mathematical rigor are not opposite dimensions of learning but can be complementary. Third, interdisciplinary and hybrid models of PBL (especially when combined with STEM models), tend to produce better results by transferring and applying knowledge of mathematical concepts. Fourth, the quality of implementation has a strong impact on the effectiveness of PBL, such as the scaffolding of teachers, the design of projects, the activities of formative assessment, and the support of the institution.

Despite these positive findings, there are a number of limitations of this review that should be acknowledged. The included studies were quite heterogeneous in terms of the duration of the interventions, sample size, and evaluation instruments which limits direct comparability and generalizability of results. In addition, a lot of the empirical evidence is concentrated in specific regional contexts, in this case Southeast Asia, with less studies in other parts of the world. Finally, inconsistencies at the level of operationalization and measurement of mathematical reasoning and creativity across studies limit the power of cumulative conclusions.

Based on the reviewed evidence, several practical implications emerge. For teachers, PBL should be integrated as an ongoing instructional strategy rather than a standalone activity, and projects should be designed to incorporate analytical reasoning and creative problem-solving. Curriculum developers and educational institutions should encourage the use of PBL combined with STEM through adequate time, resources, and interdisciplinary collaboration. At the policy level, recognizing that creativity and complex problem-solving are vital learning outcomes, along with investing in teacher professional development, is essential for the effective implementation of PBL.

Future research should address the identified limitations, such as conducting longitudinal studies and multi-site studies, creating more standardised instruments for assessing mathematical reasoning and creativity, and studying the implementation of PBL in underrepresented and digital-mediated learning environments. Overall, this systematic review adds to the literature in terms of clarifying how and under what circumstances PBL supports the joint development of mathematical reasoning and creativity providing evidence-based guidance for researchers, educators, and policy makers.

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