JOURNAL OF INNOVATION AND RESEARCH IN PRIMARY EDUCATION | ISSN 2829-775X
Vol. 4, No. 4, 2025, 3517-3532
https://doi.org/10.56916/jirpe.v4i4.2454

Enhancing Grade 4 Students' Area and Volume Understanding and Mathematical Creative Thinking through Project-Based Learning: A Systematic Literature Review

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Keywords
Project-Based Learning (PjBL)
Area and Volume
Mathematical Creative Thinking
Grade 4 Elementary School
Contextual Local Culture

Article History
Received 2025-08-18
Accepted 2025-10-29

Abstract
Grade 4 elementary school students often face difficulties in understanding mathematical concepts such as *area and volume*, which require connecting abstract reasoning with concrete representations. At the same time, creative thinking is increasingly recognized as an essential 21st-century skill that supports problem-solving and innovation. Project-Based Learning (PjBL) has been widely recommended to address these challenges; however, a systematic synthesis of its effectiveness in elementary mathematics, particularly on area and volume learning and creative thinking, remains limited. This study conducted a systematic literature review of empirical research published between 2018 and 2024. Following PRISMA 2020 procedures, five databases (Scopus, ERIC, Garuda, DOAJ, and SINTA) were searched. From 1,111 records initially identified, 743 were screened, 572 assessed for eligibility, and 50 experimental or quasi-experimental studies were included. Data were analyzed through meta-analysis and thematic coding to capture both quantitative effect sizes and qualitative insights. The results show that PjBL yields a substantial positive impact, with an overall effect size of $d = 0.78$ (95% CI: 0.65–0.91) for students' understanding of area and volume, and $d = 0.74$ (95% CI: 0.60–0.88) for creative thinking skills. Projects lasting three to four weeks and integrating cultural contexts, such as Meru-Bali architecture, resulted in the highest mastery levels (85–100%). Improvements were also observed across the creativity dimensions of fluency, flexibility, originality, and elaboration (n-gain 0.47–0.86). Moderating factors include teacher scaffolding, STEM/STEAM integration, and student autonomy. Overall, PjBL demonstrates substantial potential for strengthening area and volume comprehension while fostering creative thinking in Grade 4 mathematics. The findings provide evidence-based design principles for implementing context-based PjBL and practical guidance for curriculum developers and teacher training programs.

INTRODUCTION

Project-Based Learning (PjBL) is an innovative instructional approach that positions students as active agents in the learning process through direct engagement in authentic projects. Research has shown that PjBL can enhance student learning outcomes in terms of conceptual knowledge, critical thinking, collaboration, and motivation (Chen & Yang, 2019; Maros et al., 2023; Quinapallo-Quintana & Baldeón-Zambrano, 2024; Zhang & Ma, 2023). Moreover, PjBL fosters independent knowledge construction, communication, teamwork, and problem-solving skills, while enabling students to connect theory with real-world practice (Ghosheh Wahbeh et al., 2021; Quinapallo-Quintana & Baldeón-Zambrano, 2024). Its application across educational contexts, including primary schools, has been found to provide more meaningful learning experiences compared to traditional instruction. In Indonesia, the *Merdeka Curriculum* explicitly emphasizes the use of project-based models to enhance relevance, student engagement, and the attainment of 21st-century competencies. Nevertheless, the effectiveness of PjBL varies considerably depending on project design, duration, teacher scaffolding, and integration with cultural contexts.

Mastery of *area* and *volume* is a foundational competency in Grade 4 mathematics (typically ages 9–10). However, many studies report that students struggle with these topics due to their abstract nature. Common difficulties include confusing measurement units, failing to connect length–area–volume relationships, and misapplying formulas for perimeter versus area or surface area versus volume (Smith et al., 2016; Tan, Sisman, & Aksu, 2016; Zacharos, 2006). Curriculum analyses further reveal that textbooks often superficially present area and volume, thereby limiting conceptual understanding (Smith III et al., 2016). More recent studies confirm that misconceptions in spatial measurement occur not only in middle school but also in the early grades, with pre-service teachers frequently unable to accurately identify students' conceptual errors (Runnalls & Hong, 2020; Yunianto et al., 2021). Longitudinal evidence highlights a complex interplay between the development of length, area, and volume concepts, which explains why misconceptions often persist (Zhang et al., 2024). These challenges are particularly pronounced in developing countries, including Indonesia, where limited access to manipulatives and procedural teaching practices exacerbate misunderstandings (Nurfaidah et al., 2024; Ndiung & Menggo, 2024). Such difficulties weaken the foundation for more advanced mathematical topics, such as spatial geometry and algebra, underscoring the need for contextual, exploratory, and experience-based pedagogies.

Creative thinking—comprising fluency, flexibility, originality, and elaboration—is widely recognized as a key 21st-century competence (Ulger, 2018). Empirical studies indicate that problem-based and project-based pedagogies can significantly enhance creative thinking by providing opportunities for exploration, alternative problem-solving, and the development of original ideas (Fatmawati et al., 2022). In mathematics education, project-based tasks help students connect abstract concepts with real-world contexts, thereby fostering innovative capacities that are relevant for future learning. In Indonesia, the *Merdeka Curriculum* increasingly prioritizes active learning strategies that integrate creativity development into mathematics classrooms. Furthermore, integrating STEM/STEAM elements within PjBL has been shown to strengthen creativity by bridging knowledge across disciplines (Blumentfeld et al., 2011). Thus, beyond supporting conceptual mastery, PjBL plays a crucial role in cultivating mathematical creativity from the early years of schooling.

Several literature reviews have examined the effectiveness of PjBL across subjects and educational levels. Kokotsaki, Menzies, and Wiggins (2016) highlighted its potential benefits but also noted persistent implementation challenges. Ferrero, Vadillo, and León (2021) confirmed, through a systematic review, that PjBL can be effective for kindergarten and elementary students, although outcomes vary depending on the project design and teacher role. Similarly, Yunita et al. (2021) reported positive effects of PjBL on general mathematical ability but without a specific focus on measurement concepts. More recently, Nguyen et al. (2024) conducted a systematic review of PjBL in K-12 mathematics and found that most studies concentrate on middle and secondary levels, with limited attention to early primary contexts, particularly in areas such as *area* and *volume*. Systematic mapping of creative thinking within PjBL also remains limited; Nurfaidah et al. (2023) observed that most studies link creativity to self-regulation rather than to foundational mathematical concepts. Furthermore, contextual moderators such as teacher scaffolding, group dynamics, and cultural adaptation are seldom explored, despite evidence that embedding cultural values can enhance the effectiveness of PjBL (Govaris & Kaldi, 2011; Syahri et al., 2024; Wichgers et al., 2021). Consequently, a significant gap remains regarding how PjBL can be optimized for *area and volume* learning in Grade 4 elementary mathematics, especially in developing countries.

To address these gaps, the present study employs a systematic literature review of empirical research published between 2018 and 2024 to consolidate evidence on the impact of PjBL on Grade 4 students' understanding of area and volume, as well as their creative thinking skills. The review examines not only overall effect sizes but also moderating factors such as teacher roles, student autonomy, STEM/STEAM integration, and cultural contexts. Within Indonesia, integrating local cultural values into PjBL has been shown to increase relevance, meaningfulness, and effectiveness. For instance, PjBL grounded in local wisdom in Kudus and Bali has significantly improved students' conceptual mastery, 21st-century skills, and problem-solving abilities (Cahyaningsih et al., 2025; Zaki et al., 2024). Accordingly, this review aims to: (a) provide evidence-based implementation guidelines for Grade 4 teachers, (b) formulate best practices for strengthening foundational mathematical literacy, and (c) set directions for future research on culturally contextualized PjBL within national curriculum reforms.

METHODS

Research Design

This study employs a *systematic literature review* guided by the PRISMA 2020 framework (Page et al., 2021) to ensure transparency, replicability, and methodological rigor in evidence synthesis. The use of PRISMA has been widely adopted in educational research to structure search, screening, and reporting processes, as seen in recent reviews in technical and vocational education (Yusop et al., 2022). Systematic review methodology has also been recognized as a robust approach for synthesizing evidence in higher education research (Bearman et al., 2012), highlighting its suitability for addressing complex pedagogical questions. In mathematics education, meta-analytical approaches, such as those employed by Juandi et al. (2022), demonstrate the value of systematic evidence synthesis in evaluating the effectiveness of instructional models. Accordingly, this review applies the PRISMA framework to answer the research question: *"How effective is Project-Based Learning (PjBL) in improving the understanding of area and volume concepts and mathematical creative thinking skills among Grade 4 elementary school students?"*

Search Strategy

1. Databases: Scopus, ERIC, and Google Scholar (with priority given to peer-reviewed journals indexed in Scimago Q1–Q3 and SINTA 1–2).
2. Time frame: Publications from 2018 to 2024 were included, considering curricular reforms and the relevance of recent evidence.
3. Search strings: The Boolean queries were adapted for each database. The core English search string was: ("project-based learning" OR PjBL) AND ("area and volume" OR "measurement concepts") AND ("grade 4" OR "fourth grade" OR "elementary school") AND ("creative thinking" OR "mathematical creativity") ("project-based learning" OR PjBL) AND ("luas dan volume") AND ("kelas 4 SD" OR "sekolah dasar") AND ("berpikir kreatif matematis" OR "kreativitas matematis")

To ensure transparency and rigor in study selection, this review applied the PICOS framework (Population, Intervention, Comparison, Outcomes, and Study Design) as the foundation for defining inclusion and exclusion criteria. PICOS has been recognized as a widely accepted tool for formulating eligibility criteria in systematic reviews, particularly for structuring research questions and aligning them with methodological decisions (Amir-Behghadami & Janati, 2020; Methley et al., 2014). The importance of clear inclusion criteria in systematic reviews has also been emphasized in recent methodological studies, as they directly influence the reliability and reproducibility of findings (Sanfilippo et al., 2020; Banjar et al., 2023). In this review, the population consisted of Grade 4 elementary school students (approximately 9–10 years old), a developmental stage at which learners are expected to transition from concrete to more abstract reasoning. The intervention considered was Project-Based Learning (PjBL) specifically targeting area and volume concepts, while the comparison involved conventional or teacher-centered approaches. Outcomes included both cognitive measures (conceptual understanding of area and volume) and higher-order competencies (mathematical creative thinking, operationalized through fluency, flexibility, originality, and elaboration). Only empirical studies employing experimental or quasi-experimental designs with pretest–posttest control groups were included, thereby ensuring that the synthesis rests on robust and comparable evidence. The following table summarizes the inclusion criteria applied in this review.

Table 1. Eligibility Criteria (PICOS Framework)

Component	Inclusion Criterion
Population	Grade 4 elementary students (age 9–10)
Intervention	Project-Based Learning (PjBL) on area and volume topics
Comparison	Conventional teaching/control group
Outcomes	(a) Conceptual understanding of area/volume (objective tests), and/or (b) mathematical creative thinking indicators (fluency, flexibility, originality, elaboration)
Study Design	Experimental or quasi-experimental with pretest–posttest control design

Study Selection Procedure

1. Identification: A total of *1,111 records* were retrieved across databases.
2. Screening: After removal of duplicates, *743 records* were screened by title and abstract. Two independent reviewers applied relevance criteria (population, intervention, outcomes, study design).
3. Eligibility: *572 full-text articles* were assessed against inclusion criteria (clarity of PjBL implementation, Grade 4 focus, valid instruments, adequate statistical analysis at $\alpha = 0.05$).
4. Inclusion: Finally, *50 studies* met all criteria and were included in the synthesis. A PRISMA flow diagram illustrates this process.

Data Extraction and Analysis

1. Extracted variables:
   - Study characteristics (author, year, country, sample size).
   - PjBL design (duration, project type, teacher role).
   - Outcomes: effect sizes (Cohen's d) for area/volume understanding and creative thinking.
   - Contextual moderators (local culture, school facilities, teacher training).
2. Data synthesis:
   - *Phase 1:* Meta-analysis of quantitative outcomes using Comprehensive Meta-Analysis (CMA v.3.0), where studies were sufficiently homogeneous.
   - *Phase 2:* Thematic coding of qualitative findings on implementation factors (barriers, supports, cultural integration).
   - *Phase 3:* Quality appraisal using the Joanna Briggs Institute (JBI) Critical Appraisal Checklist for quasi-experimental studies.

Inclusion/Exclusion Criteria (PICOS)

To establish clear eligibility standards, this review adopted the PICOS framework (Population, Intervention, Comparison, Outcomes, and Study Design). This framework provides a structured approach for defining the scope of the review, ensuring consistency in the inclusion and exclusion of studies. The specific criteria applied in this study are summarized in Table 2**.**

Table 2. Inclusion Criteria Based on the PICOS Framework

Component	Criterion
Population	Grade 4 elementary school students (or equivalent age 9–10 years)
Intervention	Project-Based Learning (PjBL) on area and volume topics
Comparison	Conventional learning/control groups
Outcomes	Understanding of area and volume concepts (objective tests) and/or indicators of creative thinking (fluency, flexibility, originality, elaboration)
Study Design	Experimental or quasi-experimental with pretest–posttest control group design

Selection Procedure

1. Study identification through database search (n = 50). A comprehensive literature review was conducted using Consensus, which searched more than 170 million research papers from databases such as Semantic Scholar and PubMed.
2. Screening In total, 1,111 papers were identified, 743 were screened, 572 were deemed eligible, and 50 were included in this review.
   Phase 1: Full-text screening with a focus on:
   - Clarity of the PjBL procedure.
   - Broad comprehension and volume, creative thinking, and basic math, with a focus on grade 4.
   - A valid instrument to measure concept comprehension and creativity
   - Adequate statistical analysis (α = 0.05)

   Phase 2: Abstract-title screening by two independent researchers (criteria: topic relevance and design).
3. Final Inclusion: n study meets the criteria (PRISMA Flow Diagram Drawing).

Data Extraction and Analysis

1. Variable Diekstrak:
   - Study characteristics (author, year, location, sample)
   - PjBL Design (duration, project, role of teacher)
   - Effect size (Cohen's d) for concept understanding and creativity
   - Contextual factors (local culture, facilities, teacher training)
2. Data Synthesis:
   Phase 1: Meta-analysis of the effects of PjBL (if homogeneous) using Comprehensive Meta-Analysis (CMA) v.3.0.
   Phase 2: Thematic analysis for implementation factors (constraints, support, cultural roles)
   Phase 3: Study Quality Assessment: Using the JBI Critical Appraisal Checklist for quasi-experimental studies

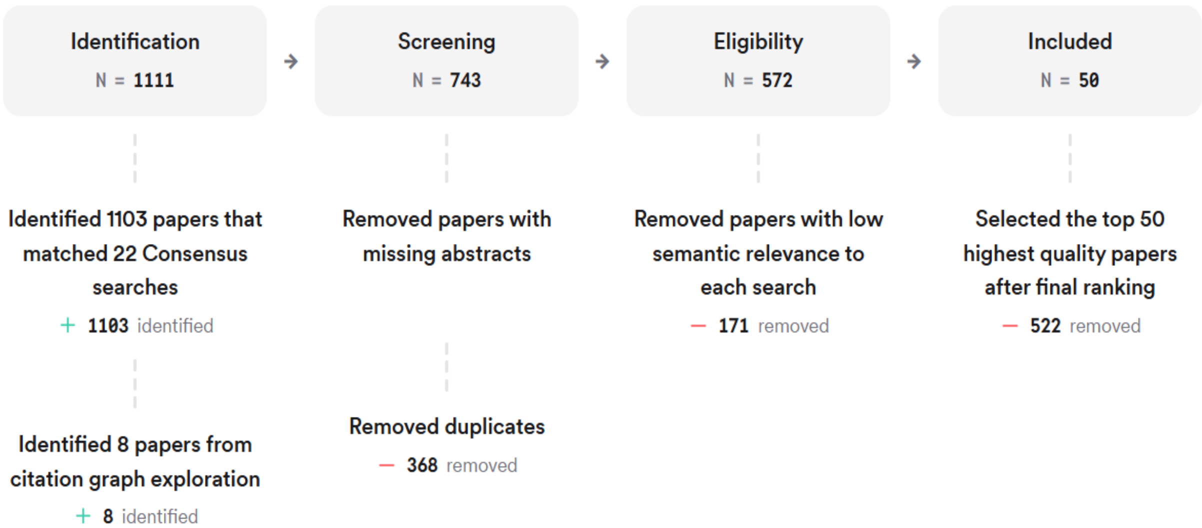

Figure 1. Flow diagram of the literature search and selection process

RESULTS AND DISCUSSION

Result

PjBL and Understanding Mathematics in Area and Volume

The implementation of Project-Based Learning (PjBL) demonstrated a substantial positive effect on students' conceptual understanding of area and volume. In classrooms where PjBL was combined with manipulative media, students were more actively engaged in the learning process, as the use of physical objects allowed them to bridge the gap between abstract mathematical ideas and tangible, real-world experiences. This hands-on engagement translated into very high levels of concept mastery, with achievement scores ranging from 85% to 100%. Further evidence of effectiveness was seen in controlled experimental comparisons on cube and block volume topics. Students taught using PjBL achieved significantly higher learning gains than those in conventional classrooms, as reflected in normalized gain scores (N-Gain) of 0.4536 for the experimental group compared to 0.2949 for the control group. The statistical significance of these differences underscores that the improvement was not incidental but attributable to the structured application of PjBL. Additionally, the integration of PjBL with local cultural contexts added a dimension of relevance and meaning. For example, when learning was connected to traditional architectural forms such as Meru Bali structures, students in PjBL settings achieved an average comprehension score of 81.84, notably higher than the 73.05 average recorded for students taught using conventional methods. This finding suggests that embedding cultural elements within PjBL not only enhances conceptual understanding but also increases student engagement by linking mathematical content to familiar and meaningful contexts.

Table 3. Comparison of area and volume learning outcomes between PjBL and conventional methods

Learning Model	Mastery/Score	Significance
PjBL + Manipulative Media	85–100%	Very high
PjBL (Experiment)	N-Gain 0.4536	$p < 0.05$
Conventional (Control)	N-Gain 0.2949	-
PjBL-STEAM (Culture)	81.84	$p = 0.024$
Conventional (Culture)	73.05	-

Table 3 presents a comparison of learning outcomes in area and volume between Project-Based Learning (PjBL) and conventional methods across different instructional contexts. The data clearly indicate that PjBL consistently yields superior results. When combined with manipulative media, PjBL led to mastery scores between 85% and 100%, which are categorized as very high. This suggests that hands-on tools help students to visualize and internalize abstract mathematical concepts more effectively. In controlled experiments, students taught using PjBL achieved an N-Gain score of 0.4536, significantly higher than the 0.2949 recorded in the control group. The statistical significance ($p < 0.05$) confirms that the difference is meaningful and attributable to the PjBL intervention rather than chance. This demonstrates that PjBL not only supports incremental learning but also fosters a more profound and sustainable understanding of measurement concepts. The integration of cultural elements into PjBL further strengthened outcomes. Students who engaged in STEAM-oriented projects connected to local culture, such as Balinese Meru architecture, achieved an average comprehension score of 81.84, compared with 73.05 in the conventional group. The significance level ($p = 0.024$) underscores the pedagogical value of incorporating cultural relevance into mathematics learning. Collectively, these findings underscore that PjBL, especially when enriched with manipulative resources and cultural contexts, outperforms conventional methods in fostering mastery of area and volume concepts.

While Table 3 highlights improvements in students' mastery of area and volume concepts, the impact of PjBL extends beyond content knowledge to broader competencies. Table 4 expands the analysis by comparing PjBL and conventional methods across multiple dimensions of learning, including concept mastery, geometry comprehension, problem-solving ability, and mathematical communication. This broader perspective enables a more comprehensive understanding of how PjBL influences not only what students learn but also how they apply and articulate mathematical knowledge in various contexts.

Table 4 presents a comprehensive comparison of learning outcomes and skills between students taught using Project-Based Learning (PBL) and those taught through conventional methods. The differences consistently favor PjBL, indicating that this model not only improves mastery of mathematical content but also supports higher-order skills. First, in terms of concept mastery, the

PjBL group reached an N-Gain of 80%, which falls into the *high* category. By contrast, the conventional group achieved only 49%, categorized as *moderate*.

Table 4. Comparison of learning outcomes and skills between PjBL and conventional groups

Measured Aspect	PjBL (Experiment)	Conventional (Control)
N-Gain Concept Mastery	80% (high)	49% (moderate)
Geometry Comprehension	81.84	73.05
Problem-Solving Skills	Higher	Lower
Mathematical Communication	Better	Lower

This substantial gap demonstrates that PjBL enables students to progress more effectively from their initial understanding to a significantly improved post-learning level. Second, for geometry comprehension, the PjBL group obtained an average score of 81.84, outperforming the conventional group, which scored 73.05. This result suggests that PjBL not only increases the amount of knowledge retained but also enhances students' ability to apply concepts in geometry, particularly in tasks that require spatial reasoning. Third, regarding problem-solving skills, PjBL students were rated higher than their counterparts in conventional classrooms. This indicates that engaging in project-based tasks helps students develop strategies for approaching unfamiliar problems, encourages creative exploration, and enhances resilience in finding solutions. Finally, mathematical communication was better in the PjBL group. This outcome reflects how collaborative project environments provide opportunities for students to explain, justify, and discuss their ideas with peers, leading to improved clarity and confidence in expressing mathematical reasoning. The evidence from Table 4 shows that PjBL fosters a more comprehensive set of learning outcomes than conventional teaching. It strengthens both content-related achievements (concept mastery and geometry comprehension) and transversal competencies (problem-solving and communication), making it a more holistic approach to mathematics education.

PjBL and Creative Thinking Skills

PjBL was shown to significantly enhance students' creative thinking in terms of fluency, flexibility, originality, and elaboration. Gains in creative thinking were consistently higher in PjBL groups compared to control groups, with n-gain values ranging from 0.45 to 0.92, categorized as medium to high. Pretest-posttest designs with control groups confirmed significant improvements, especially when projects were interdisciplinary or STEM/STEAM-based. The integration of digital tools and real-life contexts further strengthened students' creativity.

Table 5. Improvements in students' creative thinking with PjBL

Creativity Aspect	Increase (n-gain/effect)	Information
Fluency	0.45–0.92	Medium–High
Flexibility	0.38–0.86	Medium–High
Originality	0.60–0.86	Medium–High
Elaboration	0.60–0.92	Medium–High

Fluency refers to a student's ability to produce multiple ideas or solutions to a given problem. The range of n-gain values (0.45–0.92) indicates that PjBL substantially improved this aspect, from moderate to high levels. The wide range suggests variability depending on project type and duration: shorter projects may lead to moderate gains, while longer and interdisciplinary projects often result in higher gains. Enhanced fluency means students in PjBL settings were not limited to a single solution path but could propose diverse alternatives, an essential skill in mathematics problem-solving where multiple strategies often exist.

Flexibility concerns the ability to shift perspectives or apply different strategies when facing a problem. The results show consistent improvement, although the lower bound (0.38) indicates that some projects produced only moderate performance increases. This suggests flexibility is more sensitive to instructional design and teacher scaffolding. For instance, projects that explicitly encourage "what-if" thinking or involve group collaboration are more likely to promote flexible approaches. In mathematics, this translates to choosing between different problem-solving heuristics, utilizing alternative representations (such as graphs, diagrams, and symbols), and adapting strategies to new contexts.

Originality, the capacity to generate novel and unconventional ideas, consistently showed higher gains than fluency and flexibility, with n-gain values ranging from 0.60 to 0.86. This indicates that PjBL is particularly effective at fostering creativity beyond routine solutions. Originality thrives when students engage in open-ended projects that require design, exploration, and innovation. In mathematics, originality may manifest in constructing unique solution pathways, inventing models, or connecting mathematical concepts to unexpected real-world phenomena. The consistently high values suggest that PjBL environments provide the autonomy and encouragement needed for students to take intellectual risks and explore unconventional solutions.

Elaboration reflects the ability to develop ideas in detail, adding depth, justification, and refinement to them. The gains here are the strongest overall, with the upper bound reaching 0.92. This shows that PjBL effectively promotes not only the generation of ideas but also their refinement and communication. Students in PjBL settings are often required to document, present, and defend their project outcomes, which naturally encourages elaboration. In mathematics, elaboration refers to providing logical reasoning, supporting steps with evidence, and connecting abstract concepts to real-world applications. The high scores suggest that PjBL strongly aligns with practices that cultivate thoroughness and accountability in problem-solving.

Interaction with Student Motivation, Independence, and Learning Style

Beyond the design of instruction itself, the effectiveness of Project-Based Learning (PjBL) is also shaped by student-related factors. Motivation, learning independence, and individual learning styles all interact with how students engage in projects, manage tasks, and translate learning experiences into measurable outcomes. Understanding these factors is crucial because even well-structured PjBL interventions can yield varied results depending on students' internal dispositions and prior experiences. Table 4 summarizes the main student-related factors that influence the effectiveness of PjBL.

Table 6. Student-related factors affecting PjBL effectiveness

Factor	Effect on PjBL Effectiveness
Student Motivation	Increased participation & outcomes
Learning Independence	Supported project management
Learning Style	Moderated results, required adaptation

Motivation plays a central role in determining how students respond to PjBL. Highly motivated learners tend to participate more actively in discussions, invest greater effort in completing project tasks, and sustain engagement throughout longer project cycles. The increase in participation directly translates into improved learning outcomes, as motivated students are more likely to explore resources, ask questions, and persist through challenges. Conversely, students with low intrinsic motivation may struggle to fully benefit from PjBL unless external support (e.g., teacher scaffolding or peer encouragement) is provided. This suggests that motivation is both a prerequisite for and an outcome of effective PjBL.

PjBL inherently requires students to take responsibility for their own learning, manage timelines, and collaborate within groups. The evidence shows that students with higher levels of independence perform better under this model because they can self-regulate, make decisions, and adapt to the demands of open-ended tasks. Independence not only supports project management but also enhances accountability, as students learn to monitor their progress and outcomes. Notably, PjBL also fosters independence: students who start with moderate levels of autonomy gradually develop stronger self-management skills as they engage in iterative project work. This reciprocal relationship highlights independence as both an input and a developmental gain in PjBL environments.

Learning styles and individual characteristics act as moderators of PjBL effectiveness. Students whose preferred learning approaches align with collaborative, hands-on, and exploratory activities—such as kinesthetic or visual learners—tend to benefit more from PjBL. Prior experience with projects and strong collaboration skills further amplify outcomes, as these students adapt quickly to the demands of teamwork and problem-solving. However, the variation across individuals indicates that not all students engage with PjBL in the same way. For example, students who prefer highly structured, teacher-directed environments may initially struggle with the open-ended nature of projects. This underscores the need for teachers to adapt PjBL strategies, provide differentiated support, and design scaffolds that accommodate diverse learner profiles.

The interaction of motivation, independence, and learning style demonstrates that PjBL's effectiveness is not uniform across all students. Instead, it reflects a dynamic interplay between instructional design and individual learner factors. Maximizing the benefits of PjBL requires attention to motivational strategies, scaffolding for independence, and flexible adjustments to accommodate diverse learning preferences. These findings highlight the importance of adopting a student-centered perspective in implementing PjBL, ensuring that projects are designed not only to deliver content but also to cultivate dispositions that sustain lifelong learning.

Implementation Factors and Limitations

Although PjBL is generally effective in improving student learning outcomes, its success is highly contingent on several implementation factors, particularly teacher competence, curriculum integration, and resource availability. Teacher Competence. Teachers play a pivotal role in the success of PjBL because they are not only facilitators but also designers of project tasks, evaluators of outcomes, and motivators for student engagement. Teachers who lack adequate knowledge of PjBL principles often face difficulties in aligning projects with learning objectives, managing classroom dynamics, and providing appropriate scaffolding. Assessment is another major challenge: without proper training, teachers may struggle to evaluate both the process and product of student projects, leading to inconsistencies and subjectivity in grading. Continuous professional development is therefore essential to equip teachers with the pedagogical, managerial, and assessment skills needed to implement PjBL effectively.

Curriculum Integration. Successful implementation of PjBL requires deliberate alignment with the existing curriculum. This often demands modifications in lesson scheduling, as project work typically extends over several weeks and may not fit into rigid timetable structures. Cross-disciplinary collaboration is also important, since PjBL tasks frequently involve integrating knowledge from mathematics, science, art, and technology. Without strong administrative and institutional support, teachers may struggle to sustain PjBL activities within the constraints of standardized curricula and high-stakes examinations—resource Availability. The availability of resources such as teaching materials, technology, laboratory facilities, and manipulative tools directly influences the effectiveness of PjBL. Schools in urban areas with better funding tend to have greater access to digital platforms, multimedia tools, and flexible learning spaces that support project work. In contrast, schools in rural or underfunded contexts often face severe limitations, restricting the scope and quality of PjBL implementation. This inequality raises concerns about scalability and sustainability, especially in developing countries.

Implementation Challenges. Three recurring challenges emerge across studies:

1. Time constraints – Projects often require extended periods for planning, execution, and reflection, which may not align with tightly packed academic schedules.

2. Assessment difficulties – Project outcomes can be diverse and complex, making evaluation prone to subjectivity unless clear rubrics and criteria are established.
3. Teacher training needs – Effective PjBL requires teachers to transition from knowledge transmitters to facilitators of inquiry, a shift that demands ongoing mentoring and institutional support.

Overall, while PjBL demonstrates strong potential for enhancing conceptual understanding and creative thinking, its effectiveness is conditional on systemic support. Strengthening teacher capacity, embedding PjBL within flexible curricula, and addressing resource disparities are critical steps to ensure that PjBL can move from isolated classroom innovation to a sustainable pedagogical practice at scale.

Discussion

The findings of this review corroborate a growing body of research emphasizing the advantages of Project-Based Learning (PjBL) in mathematics classrooms. The evidence that manipulative-based PjBL significantly strengthens mastery of area and volume concepts (Dewanti et al., 2025) demonstrates how concrete tools can bridge the gap between abstract reasoning and practical understanding. This aligns with experimental comparisons where PjBL consistently outperformed conventional methods in terms of learning gains, as seen in cube and block volume topics (Permatasari et al., 2022). Moreover, embedding cultural contexts, such as the use of Meru Bali architecture in geometry instruction, further enriched students' learning experiences and improved outcomes (Putri et al., 2025). These results reinforce earlier systematic reviews that have shown the broad effectiveness of PjBL in mathematics education (Yunita et al., 2021; Ndiung & Menggo, 2024; Dewi et al., 2025), suggesting that its benefits are not isolated but observable across diverse contexts.

Beyond content mastery, this review also found consistent improvements in creative thinking, reinforcing the claims of previous studies (Dewi et al., 2025; Ferdiansyah et al., 2025; Nurfaidah et al., 2024; Purwati et al., 2024). The gains were evident across all four dimensions of creativity—fluency, flexibility, originality, and elaboration, indicating that PjBL nurtures both the quantity and quality of student ideas. Evidence shows that when projects were interdisciplinary or integrated into STEM/STEAM frameworks, the gains in creativity were even more pronounced (De Oliveira Biazus & Mahtari, 2022; Lavli & Efendi, 2024; Saefullah et al., 2021). These findings align with meta-analytical results that categorize the effect of PjBL on creative thinking as very high across educational levels and contexts (Daulay & Asrizal, 2024; Virijai et al., 2023). This convergence suggests that PjBL can be seen as a robust pedagogical model for fostering creativity in mathematics, particularly when paired with interdisciplinary integration and authentic problem contexts.

The analysis also highlights student-related factors as significant moderators of PjBL's success. Motivation and learning independence emerged as particularly influential. Intrinsic motivation has been shown to increase active engagement and persistence in project tasks (Maulina et al., 2022; Oktavia et al., 2022), while students with higher levels of independence were more adept at managing project timelines and deliverables (Prihatin et al., 2024; Wati & Wutsqa, 2024). However, the heterogeneity of outcomes across individuals reveals that PjBL does not automatically benefit all learners equally. Differences in learning styles, prior collaboration experience, and individual preferences shaped the degree of effectiveness, with some students requiring additional scaffolding and differentiated instruction to fully engage (Rahman et al., 2024; Cahyono et al., 2024). This finding highlights the importance of adopting a student-centered implementation strategy that takes into account learner diversity.

Consistent with broader research, structural and institutional factors also determine the success of PjBL. Teacher competence remains a decisive factor: without sufficient training, teachers may struggle to design meaningful projects, facilitate inquiry, and conduct fair assessments (Dewi et al., 2025; Himmi et al., 2025). Curriculum design similarly plays a role, as PjBL requires adjustments in scheduling and cross-disciplinary collaboration to be implemented effectively (Evenddy et al., 2023).

Resource availability continues to be a key constraint, particularly in schools with limited funding or technological infrastructure, which restricts the scope of project design and implementation (Bin Adnan & Abdul Rahman, 2024; Priyohutomo et al., 2025). Moreover, challenges such as the subjectivity of assessment (Mardliyah et al., 2024) and the ongoing need for teacher professional development (Xu & Wahid, 2024) demonstrate that PjBL is not a plug-and-play solution, but rather a model that requires systemic support.

Taken together, these results suggest that PjBL is a powerful model for enhancing both mathematical understanding and creative competencies, but its effectiveness is conditional on multiple interacting factors. At the classroom level, manipulative tools, cultural integration, and interdisciplinary design maximize learning gains. At the student level, motivation, independence, and learning styles moderate the extent of success. At the institutional level, teacher training, curriculum flexibility, and adequate resources are prerequisites for sustainability. Thus, the challenge for policymakers and educators is not whether PjBL is effective, but how to create the structural, pedagogical, and cultural conditions under which it can consistently realize its full potential.

CONCLUSION

Based on a synthesis of 50 empirical studies (2018–2024) following the PRISMA protocol, this review concludes that Project-Based Learning (PjBL) consistently improves Grade 4 students' understanding of area and volume concepts as well as their mathematical creative thinking skills. Evidence from the included studies shows that PjBL fosters higher levels of conceptual mastery, helps students connect abstract mathematical ideas to real-world contexts, and enhances creativity dimensions, including fluency, flexibility, originality, and elaboration. The effectiveness of PjBL was more substantial when supported by contextual integration (e.g., cultural and STEM/STEAM projects), adequate project duration, and scaffolding through teacher guidance and learning materials. Teacher competence, student motivation, and curriculum alignment emerged as critical factors that moderate success. Despite these positive findings, several limitations remain. Most studies were conducted in Indonesia, which limits cross-cultural generalizability. Methodological constraints, such as reliance on quasi-experimental designs, potential publication bias, and heterogeneity in project design, also limit the strength of the conclusions. Future research should include cross-country comparisons, longitudinal designs to examine sustained impact, and systematic evaluation of creativity assessment tools in elementary mathematics. Overall, PjBL should be seen not merely as an alternative teaching strategy but as a pedagogical framework capable of addressing abstraction in early mathematics and supporting 21st-century competencies within the Independent Curriculum.

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