Project-Based Learning in Early Mathematics Education: A Recent Systematic Review

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ABSTRACT

Project-Based Learning (PBL), also commonly referred to as Project-Based Learning (PjBL), has received increasing scholarly attention in early mathematics education due to its potential to support meaningful learning, strengthen problem-solving abilities, and foster 21st-century competencies from an early age. Despite this growing interest, empirical research examining its classroom implementation, learning outcomes, and instructional challenges in early mathematics contexts remains fragmented and, in some cases, inconsistent. To address this gap, the present systematic literature review synthesises recent empirical studies on the application of PBL/PjBL in early mathematics education, with particular attention to learner outcomes, teacher readiness, and innovations in instructional design. Guided by the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines, the review analysed peer-reviewed empirical studies published between 2023 and 2025 and indexed in the Scopus and ERIC databases. Following a rigorous screening and eligibility process, 21 primary studies were retained for thematic analysis. The synthesis identified three overarching themes: (1) learning outcomes associated with PBL/PjBL, including conceptual understanding, problem-solving skills, collaboration, and creativity; (2) challenges related to teacher readiness, professional capacity, and assessment practices; and (3) innovation and design features of PBL/PjBL models, including structured scaffolding, digital integration, and context-based project design. Overall, the findings indicate that while PBL/PjBL holds considerable promise for enhancing early mathematics learning, its effectiveness is highly dependent on teacher preparation, alignment of assessment approaches, and context-sensitive instructional design. This review therefore provides a structured evidence base to inform professional development, curriculum planning, and future empirical and design-based research in early mathematics education.

Keywords: Project-Based Learning (PBL/PjBL), Early Mathematics Education, 21st-Century Skills, Teacher Readiness, Systematic Literature Review

INTRODUCTION

Project-Based Learning (PBL) has increasingly been recognised as a transformative pedagogical approach in early mathematics education, as it offers young learners more dynamic and engaging opportunities to construct mathematical understanding. In contrast to conventional instructional practices that often emphasise rote memorisation and decontextualised problem-solving, PBL foregrounds active learning by situating mathematical ideas within meaningful, real-world contexts and collaborative project activities. This orientation aligns closely with the principles of Realistic Mathematics Education (RME), which emphasise the use of authentic, real-life situations as a foundation for developing mathematical concepts (Bakait et al., 2021). When integrated into foundational mathematics instruction, PBL is intended to support deeper conceptual understanding, strengthen problem-solving abilities, and foster learner engagement and motivation throughout the learning process.

A central strength of PBL in early mathematics instruction lies in its capacity to enhance the relevance and meaningfulness of learning experiences. Within PBL-oriented classrooms, learners are engaged in projects

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that require the application of mathematical concepts to practical situations, allowing mathematics to be experienced as a functional and purposeful discipline rather than a purely abstract subject (del Valle-Ramón et al., 2020; Sheikh et al., 2011). For example, projects involving the design of a small garden may require learners to apply measurement and calculation skills to plan layouts and estimate material quantities. Such hands-on experiences not only increase learners' interest in mathematics but also contribute to the development of critical thinking and problem-solving skills that are essential for later academic learning and future professional contexts (Rozhkova et al., 2020; Uyangör, 2012).

In addition to cognitive outcomes, PBL also supports the development of cooperative learning and interpersonal communication skills, which are increasingly valued in contemporary educational contexts. In PBL settings, students typically work collaboratively to complete project tasks, a process that necessitates effective communication, the exchange of ideas, and collective problem-solving when challenges arise (Haatainen & Aksela, 2021; Lee, 2022). Through these interactions, learners develop important social-emotional competencies, including empathy, teamwork, and perseverance. Furthermore, PBL provides structured opportunities for peer learning, enabling students to benefit from one another's strengths and perspectives, thereby enriching the overall learning experience (Goldstein, 2016; Holmes & Hwang, 2016).

Despite these recognised benefits, the implementation of PBL in early mathematics education is accompanied by a number of challenges. One of the most significant challenges concerns the required shift in teachers' roles from traditional instructors to learning facilitators. This transition entails changes in established pedagogical practices and often requires additional training and sustained support to enable teachers to guide learners effectively throughout the PBL process (Gu et al., 2025.; Haatainen & Aksela, 2021). Addressing these challenges highlights the importance of providing teachers with adequate resources, targeted professional development, and opportunities for professional collaboration, particularly through platforms that support the sharing of effective practices and implementation strategies (Haatainen & Aksela, 2021; Shpeizer, 2019).

Figure 1 Conceptual Map Of Project-Based Learning In Early Mathematics Education

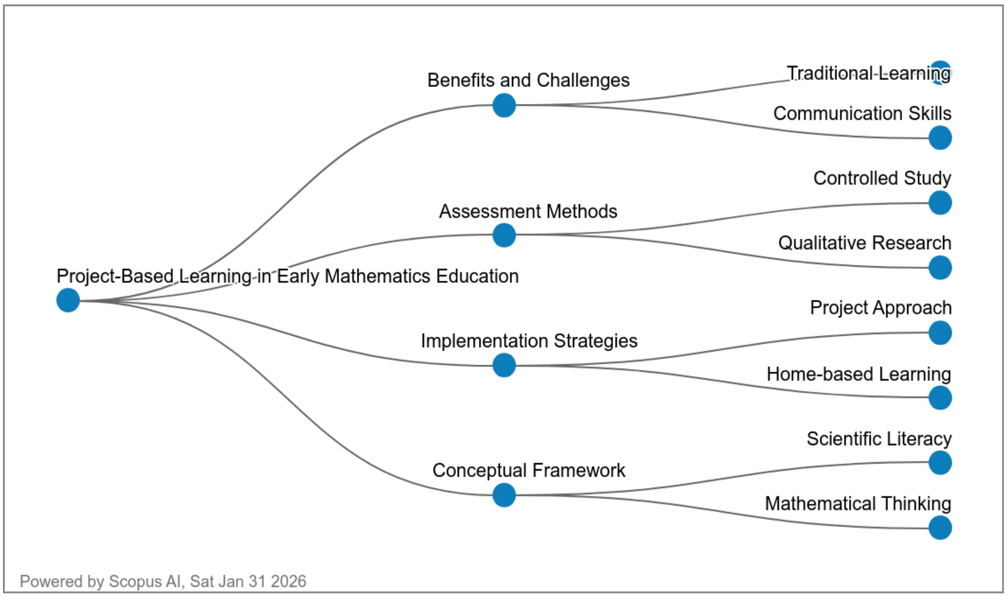

Figure 1 presents a concept map that frames the introductory focus of this study by positioning Project-Based Learning in Early Mathematics Education as the central construct, linked to four interconnected thematic domains. The first domain captures the benefits and challenges of PBL, contrasting this approach with traditional instructional practices while highlighting its potential to enhance children's communication skills alongside practical implementation constraints. The second domain addresses assessment methods, emphasising the need to move beyond controlled, test-oriented designs towards approaches that are more consistent with the exploratory and process-oriented nature of PBL. The third domain focuses on implementation strategies, including the application of the project approach and the integration of home-based learning contexts to strengthen continuity between classroom learning and children's real-life experiences. The final domain connects PBL with core learning outcomes, particularly the development of scientific literacy and mathematical thinking in early childhood. Taken together, the concept map illustrates that PBL in early mathematics education represents not merely an alternative pedagogical strategy, but a holistic approach that integrates theory, practice, assessment, and learner outcomes, thereby underscoring the need for systematic investigation and structured guidance for teachers.

Overall, PBL may be regarded as a promising instructional approach in early mathematics education due to its emphasis on learner engagement, contextual relevance, and collaborative interaction. By linking mathematical concepts to authentic real-world situations, PBL supports deeper conceptual understanding and encourages more positive attitudes towards mathematics among young learners. At the same time, effective implementation requires a deliberate pedagogical shift from instructor-centred teaching towards a facilitative mentoring role, supported by appropriate professional development and instructional resources. When these conditions are in place, and teachers receive structured guidance and training, PBL holds considerable potential to strengthen early mathematics learning and to better prepare children for the demands of an increasingly complex educational environment.

Research Question

Clearly articulated research questions play a central role in ensuring the rigour and transparency of a systematic literature review, as they define the scope of the inquiry, inform study selection, and provide a structure for the synthesis of evidence (Kitchenham, 2007; Page et al., 2021). Within systematic review research, carefully formulated research questions help to maintain alignment between review objectives, inclusion criteria, and analytical procedures, thereby contributing to greater methodological coherence and clarity in the analysis.

To facilitate the systematic development of the research questions, this review employed the PICo framework, which consists of Population, Interest, and Context (Lockwood et al., 2015). This framework is well suited to qualitative and exploratory systematic reviews, as it allows for clear identification of the phenomenon under investigation and supports a more focused synthesis of evidence within educational research settings. Guided by the PICo framework, three research questions were formulated to structure and direct the present review.

RQ1: Among early childhood learners (P), how does Project-Based Learning/Project-Based Instruction (PjBL/PBL) influence early mathematics achievement and 21st-century skills development (I) in early mathematics education settings (Co)?

RQ2: Among preschool or early-years teachers (P), what forms of readiness, professional capacity, and assessment-related challenges are associated with implementing PjBL/PBL (I) in early mathematics teaching contexts (Co)?

RQ3: Within early mathematics education environments (Co) involving young learners and teachers (P), what innovative PjBL/PBL model design features and instructional components (I) are reported to support effective implementation and learning?

MATERIAL AND METHODS

This systematic literature review was conducted in alignment with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework, a widely recognised guideline developed to promote methodological transparency, completeness, and consistency across the review process (Page et al., 2021). Following the PRISMA framework enhances the rigour and reliability of systematic reviews by offering a clear and replicable structure for the identification, screening, eligibility assessment, and final inclusion of relevant studies.

In addition, the PRISMA framework underscores the importance of incorporating high-quality studies and, where appropriate, randomised designs, given their contribution to reducing bias and strengthening evidence-based conclusions (Page et al., 2021). Adherence to these guidelines ensures that the review process remains transparent, reproducible, and methodologically sound, thereby enabling future researchers to replicate the review procedures or extend the analysis with a high degree of confidence.

To ensure broad coverage and scholarly relevance, two well-established academic databases, Scopus and ERIC, were selected as sources for the literature search. Scopus was included because of its wide coverage of high-impact, peer-reviewed international journals, whereas ERIC was chosen for its particular emphasis on education-focused and practitioner-oriented research. Using both databases in combination helps to minimise database-specific bias and supports a more comprehensive retrieval of studies relevant to Project-Based Learning in early mathematics education.

Identification

In line with the PRISMA protocol, the Identification phase represents a critical foundation for ensuring transparency, defining the scope of the review, and maintaining methodological robustness in a Systematic Literature Review (SLR). In this study, the identification process was carried out using two well-established and complementary academic databases, namely Scopus and ERIC, with the key search terms *Project-Based Learning* and *Early Mathematics*, as presented in Table 1. The initial search yielded 230 records from Scopus and 278 records from ERIC, resulting in a total of 508 identified records. This relatively large number of retrieved studies reflects the increasing scholarly interest in project-based pedagogical approaches within early mathematics education, particularly in response to recent curricular reforms that emphasise active, contextualised, and learner-centred learning experiences. Employing multiple databases at the identification stage aligns with practices commonly adopted in high-impact journals, as it helps to minimise database-related bias and increases the likelihood of capturing a broad range of disciplinary perspectives, including education, psychology, curriculum studies, and early childhood pedagogy.

Beyond the numerical count, the identification of 508 records offers a clear empirical justification for undertaking a systematic synthesis rather than relying on a narrative review. The size of the retrieved literature suggests a field that has reached a degree of conceptual development while also exhibiting considerable methodological diversity, thereby necessitating structured screening and eligibility procedures to extract robust and relevant evidence. The combined use of ERIC and Scopus further enhances the educational relevance and scholarly breadth of the dataset, as ERIC is particularly attuned to practitioner-focused and policy-informed research, whereas Scopus provides extensive coverage of high-impact, peer-reviewed international journals. Taken together, this identification strategy supports the view that the existing body of evidence on Project-Based Learning in early mathematics education is both substantial and potentially fragmented, highlighting the need for a systematic approach to map research trends, identify gaps, and generate coherent insights to inform future research, pedagogical design, and curriculum development.

Table 1 The Search String

Scopus	TITLE-ABS-KEY (("project based learning" OR "project-based learning" OR "PBL" OR "project-approach" OR "hands-on learning") AND ("early mathematics" OR "early math" OR "mathematics education" OR "mathematical skills" OR "numeracy")) AND (LIMIT-TO (DOCTYPE , "ar")) AND (LIMIT-TO (LANGUAGE , "English")) AND (LIMIT-TO (PUBYEAR , 2023) OR LIMIT-TO (PUBYEAR , 2024) OR LIMIT-TO (PUBYEAR , 2025)) Date of Access: Jan 2026
ERIC	("project based learning" OR "project-based learning" OR "PBL" OR "project-approach" OR "hands-on learning") AND ("early mathematics" OR "early math" OR "mathematics education" OR "mathematical skills" OR "numeracy") **Date of Access: Jan 2026**

Screening

Following the Identification phase, the Screening stage was conducted to refine the initial pool of studies in line with the PRISMA framework and to ensure both methodological and contextual relevance to the objectives of the review. At this stage, the titles and abstracts of the 508 identified records were systematically reviewed using predefined inclusion and exclusion criteria, as outlined in Table 2. As a result of this process, 117 records from Scopus and 72 records from ERIC were retained, resulting in a total of 189 records after screening. In parallel, 319 records were excluded based on clearly defined criteria, including publications written in languages other than English, studies published prior to 2022, and document types such as conference proceedings, books, review articles, and articles categorised as "in press." The application of these criteria was intended to prioritise recent, empirical, and peer-reviewed journal articles that reflect contemporary pedagogical discourse and current developments in Project-Based Learning and early mathematics education.

The exclusion of non-empirical and outdated sources is methodologically justified by the rapid developments in early childhood pedagogy and ongoing curriculum reforms over the past decade, which have substantially influenced instructional practices and learning expectations. Restricting the review to studies published from 2023 onwards ensures closer alignment with contemporary theoretical orientations, advances in digital integration, and learner-centred pedagogical approaches that currently characterise early mathematics education. In addition, the removal of 25 duplicate records further enhanced the integrity of the dataset by preventing the repeated representation of identical studies retrieved across different databases. Taken together, the outcomes of the screening process demonstrate a deliberate balance between inclusiveness and methodological rigour, resulting in a refined body of evidence that reflects both scientific credibility and contextual relevance. This screening step not only strengthens the transparency and reproducibility of the systematic literature review but also establishes a coherent foundation for the subsequent eligibility and inclusion phases, where more detailed methodological evaluation and thematic synthesis can be undertaken.

Table 2 The Selection Criterion Is Searching

Criterion	**Inclusion**	**Exclusion**
Language	English	Non-English
Time line	2023 – 2025	< 2022
Literature type	Journal (Article)	Conference, Book, Review
Publication Stage	Final	In Press
Subject	Social Science & Mathematics	Besides Social Science & Mathematics

Eligibility

During the Eligibility phase of the PRISMA-guided review, a full-text assessment was undertaken to evaluate the substantive relevance and methodological appropriateness of the studies that had passed the screening stage. Of the 189 records retained after screening, 171 articles were available for full-text review, allowing for a more rigorous appraisal that extended beyond information provided in titles and abstracts. At this stage, particular attention was given to the extent to which each study aligned with the core objectives of the review, especially its explicit focus on Project-Based Learning within early mathematics education. Following this detailed evaluation, 153 articles were excluded from further consideration. The main reasons for exclusion included studies that fell outside the disciplinary boundaries of early mathematics or early childhood education, articles with conceptually vague titles or only peripheral relevance to the review focus, and abstracts that failed to demonstrate a clear connection to the stated research objectives. These exclusion decisions highlight the necessity of moving beyond surface-level relevance in order to ensure conceptual coherence and analytical depth within the final body of evidence.

In addition to thematic alignment, access to full-text articles constituted an essential criterion during the eligibility stage. Availability of complete manuscripts was required to allow thorough evaluation of research design, data collection methods, analytical rigour, and the credibility of reported findings. Studies for which full-text access could not be obtained were therefore excluded in order to uphold standards of transparency and quality assurance. Although this decision led to a considerable reduction in the number of eligible studies, such selectivity was necessary to minimise interpretive bias and to ensure a complete and reliable synthesis of evidence. Moreover, the relatively high exclusion rate reflects the broad and interdisciplinary use of Project-Based Learning terminology, whereby not all studies labelled as PBL directly or substantively address outcomes related to early mathematics education.

Data Abstraction and Analysis

An integrative analysis approach was employed to systematically examine and synthesise evidence drawn from a range of qualitative studies. The purpose of this analysis was to identify key themes and subthemes that were directly relevant to the focus of the review. Theme development commenced with a process of data familiarisation and organisation. As illustrated in Figure 2, the 21 selected publications were examined in detail, with relevant statements and supporting evidence extracted in relation to the central focus of the study. Particular attention was given to studies that explicitly addressed Project-Based Learning in Early Mathematics Education, especially with regard to their methodological approaches and reported learning outcomes.

Following the initial stages of coding and evidence extraction, the authors worked collaboratively to generate preliminary themes that were grounded in the contextual and empirical patterns observed across the selected studies. Throughout the analytical process, an audit log was consistently maintained to record key analytical decisions, reflections, emerging interpretations, and critical questions, thereby strengthening transparency and analytical rigour. In the final stage of analysis, the identified themes were systematically compared and cross-checked to identify potential overlaps or inconsistencies within the thematic structure. Any discrepancies or differences in interpretation were addressed through iterative team discussions and consensus-building, ensuring coherence, credibility, and validity in the development of the final themes.

Quality of Appraisal

In accordance with methodological guidelines for systematic literature reviews outlined by Kitchenham and Charters (Kitchenham, 2007), the quality of the selected primary studies was systematically assessed to determine their methodological soundness and to support meaningful quantitative comparison. To achieve this, the present review employed a structured quality assessment framework adapted from Abouzahra et al. (2020), which consists of six predefined quality assessment (QA) criteria aligned with the specific objectives of the review.

Each criterion was assessed using a standardized three-point scale: "Yes" (Y = 1) for fully met criteria; "Partly" (P = 0.5) for partially met criteria with minor limitations; and "No" (N = 0) for unmet criteria. This consistent scoring approach enhanced appraisal reliability and enabled robust comparative analysis of included studies.

i. QA1. Is the purpose of the study clearly stated?

ii. QA2. Is the interest and the usefulness of the work clearly presented?

iii. QA3. Is the study methodology clearly established?

iv. QA4. Are the concepts of the approach clearly defined?

v. QA5. Is the work compared and measured with other similar work?

vi. QA6. Are the limitations of the work clearly mentioned?

Each expert independently assessed the selected studies using the established quality assessment criteria, after which individual scores were combined to produce an overall quality rating. For a study to be retained for

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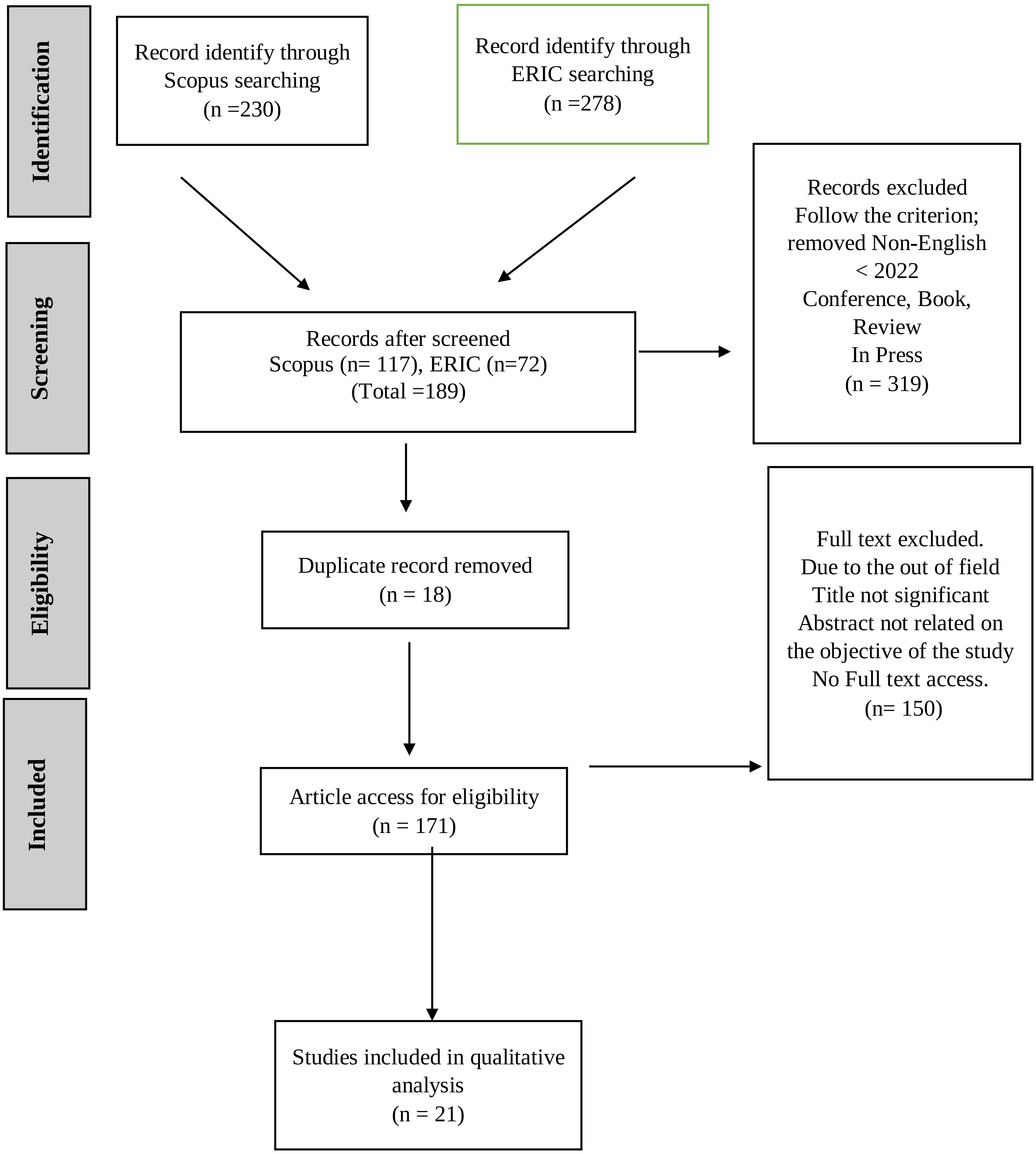
subsequent stages of the review, it was required to obtain a cumulative score exceeding 3.0 based on the aggregated evaluations of the three experts. This predetermined threshold functioned as a quality control mechanism, ensuring that only studies demonstrating an acceptable level of methodological rigour were included in the subsequent analysis.

Figure 2 Flow Diagram Of The Proposed Searching Study



RESULT AND DISCUSSION

Table 3 reports the quality assessment outcomes for the 21 primary studies (PS1–PS21) included in this review. Overall, the appraisal shows that most of the selected studies satisfied acceptable standards of methodological quality and reporting based on the six predefined quality assessment (QA) criteria. The majority of the articles clearly articulated their research objectives (QA1) and methodological approaches

(QA3), and provided sufficient definitions of the key concepts or instructional approaches under investigation (QA4), indicating a generally strong alignment between research aims, study design, and conceptual framing. Several studies further demonstrated a high level of scholarly rigour by explicitly situating their findings within the existing body of literature (QA5) and, in a smaller number of cases, by acknowledging study limitations (QA6), which contributed to overall quality scores exceeding 80%. A smaller subset of studies achieved moderate quality ratings, ranging from 50% to 75%, most often due to partial reporting of research significance, limited engagement with comparative literature, or the absence of clearly stated limitations in the abstract. Notably, no study with a quality score below 50% was retained in the review, as articles falling below this threshold were excluded to maintain the robustness, credibility, and reliability of the evidence base. This quality screening process therefore reinforces the integrity of the review by ensuring that only methodologically sound, clearly reported, and contextually relevant studies inform the synthesis and interpretation of findings. Here is the quality assessment table for the selected papers:

Table 3 Performance of Quality Assessment

PS	QA1	QA2	QA3	QA4	QA5	QA6	Total Mark	Percentage (%)
PS1 (Pham et al., 2025)	Y	Y	Y	Y	P	N	4.5	75.00
PS2 (Nasution et al., 2025)	Y	P	Y	P	N	N	3.0	50.00
PS3 (Gu et al., 2025)	Y	Y	Y	Y	Y	P	5.5	91.67
PS4 (Saparbayeva et al., 2025)	Y	Y	Y	Y	Y	N	5.0	83.33
PS5 (Elsayed et al., 2025)	Y	P	Y	P	N	N	3.0	50.00
PS6 (Lavado-Anguera et al., 2025)	Y	Y	Y	Y	P	Y	5.5	91.67
PS7 (Zetriuslita et al., 2025.)	Y	P	Y	P	N	N	3.0	50.00
PS8 (Wang & Somasundram, 2025)	Y	P	Y	Y	Y	N	4.5	75.00
PS9 (Anugraheni et al., 2025)	Y	P	Y	Y	Y	N	4.5	75.00
PS10 (Alashwal & Barham, 2025)	Y	P	Y	Y	Y	P	5.0	83.33
PS11 (Winarni et al., 2025)	Y	P	Y	P	P	P	4.0	66.67
PS12 (Nurin et al., 2024)	Y	P	Y	Y	N	P	4.0	66.67
PS13 (Zakaria et al., 2024)	Y	P	Y	Y	N	N	3.5	58.33
PS14 (Setiyani et al., 2024)	Y	P	Y	P	N	N	3.0	50.00
PS15 (Muzakkir et al., 2024)	Y	P	Y	Y	N	N	3.5	58.33
PS16 (Sumarno et al., 2024)	Y	P	Y	P	P	N	3.5	58.33
PS17 (Ahmad et al., 2023)	Y	P	Y	P	P	N	3.5	58.33
PS18 (Ranmechai & Poonputta, 2023)	Y	P	Y	P	N	P	4.0	66.67
PS19 (Drobnič Vidic, 2023)	Y	Y	P	Y	Y	P	5.0	83.33
PS20 (Alenezi, 2023)	Y	P	Y	Y	Y	P	5.0	83.33

PS21 (Jailani et al., 2023)	Y	P	Y	Y	P	N	4.5	75.00

PBL/PjBL Outcomes on Learners' Mathematics and 21st-Century Skills

Across the reviewed abstracts, the reported findings point to a broadly consistent pattern, whereby project-oriented and problem-oriented pedagogical approaches in mathematics are associated with measurable improvements in mathematical performance as well as the development of transferable competencies commonly framed as 21st-century skills. Reported achievement outcomes encompass mathematics proficiency, task-based performance, and mastery of domain-specific knowledge. For example, large-sample quasi-experimental evidence shows that project-based learning can generate substantial improvement in mathematics proficiency relative to lecture-based instruction, with an overall effect size reported as large in technical university settings (Saparbayeva et al., 2025). In skills-oriented mathematics courses, integration of STEM problem-based structures with digital tools is associated with improved problem-solving ability, suggesting that authentic tasks plus technology-supported exploration can strengthen applied mathematical reasoning (Wang & Somasundram, 2025). Similar achievement-related benefits appear in school contexts where project-based learning is implemented through an online learning platform, with higher test scores in achievement and problem-solving and also a more positive attitude toward mathematics compared to conventional instruction (Alenezi, 2023). Although the settings differ (vocational, secondary, and technical higher education), the discussion in the abstracts aligns around one mechanism: mathematical learning becomes more durable when tasks require construction of a product, interpretation of contextual information, and explanation of solutions, rather than reproduction of procedures. In elementary contexts, realistic problem-based learning is linked to improved mathematical connection abilities across sub-dimensions, indicating that contextual problem structures may help learners connect representations, concepts, and applications more coherently than conventional teaching approaches (Anugraheni et al., 2025). Together, these findings support the theme that PBL/PjBL approaches are associated with both improved mathematics outcomes and strengthened capacities for applying mathematics beyond routine exercises (Saparbayeva et al., 2025; Wang & Somasundram, 2025; Alenezi, 2023).

Beyond academic achievement, the abstracts also highlight a range of learner outcomes that align closely with commonly referenced 21st-century skills frameworks. These outcomes include creative and critical thinking, the development of productive habits of mind, representational competence, perseverance, and learner motivation. Creative thinking indicators (fluency, flexibility, originality, elaboration) are explicitly targeted in a modified project-based model applied to geometry tasks, where learner products show variation in valid solution designs and moderate overall creative performance, implying that open-ended design requirements can surface diverse mathematical strategies and support creativity-related competencies (Nasution et al., 2025). Habits of mind outcomes are also emphasized, with project-web learning over a 15-week period showing statistically significant pre–post gains across a multi-dimensional habits-of-mind scale in mathematics methods coursework, which positions online-supported PBL as a route to developing productive dispositions alongside content knowledge (Elsayed et al., 2025). Critical thinking–numeracy growth is reported in a mixed-method design where a problem-based model supported by an Autograph approach yields significant pre–post improvement, and qualitative triangulation attributes part of the growth to higher engagement and motivation during learning activities (Zetriuslita et al., 2025.). At the primary level, sustained PBL exposure across two academic years is associated with the strongest gains in mathematical problem solving, and teacher interviews describe development of perseverance, reasoning, and flexible use of representations, suggesting that longer implementation may be important for stabilizing these competencies rather than producing short-lived effects (Alashwal & Barham, 2025). Representation competence and self-confidence are also discussed as linked outcomes under problem-based models, where stronger representation competence is reported in an experimental group and self-confidence and habits of mind are described as influencing representation performance (Ahmad et al., 2023). Complementary evidence appears in bilingual project-based materials that improve literacy and numeracy, indicating that project-based structures may support dual outcomes (mathematical competence and language-related literacy) when tasks require reading, documenting, and presenting mathematical ideas (Sumarno et al., 2024). Overall, the abstracts' discussion sections collectively frame PBL/PjBL as a pedagogy that can simultaneously raise mathematical outcomes and cultivate broad competencies through authentic tasks, iterative problem solving, and reflective work products (Nasution et al., 2025; Elsayed et al., 2025; Alashwal & Barham, 2025).

Teacher Readiness, Professional Capacity, and Assessment Challenges in PBL/PjBL

The literature consistently identifies teacher readiness as a fundamental determinant of effective Project-Based Learning (PBL) and its related variants in mathematics education, particularly as instructional practices shift towards student-centred, inquiry-driven, and assessment-intensive approaches. Empirical studies indicate that teacher readiness is a multidimensional construct encompassing elements such as confidence, professional perceptions, organisational capacity, and the availability of institutional support. Pham et al. (2025), for example, identify six validated latent factors influencing PjBL implementation, including readiness for PjBL, teachers' confidence, and their capacity to organise and manage projects. Their findings emphasise that positive perceptions of PjBL alone are insufficient in the absence of adequate structural and pedagogical preparedness. Readiness, therefore, functions as both a cognitive and practical framework that shapes how teachers translate curriculum objectives into classroom implementation. Supporting this view, Winarni et al. (2025) report that prospective mathematics teachers frequently encounter difficulties when applying numeracy concepts to contextualised tasks, largely due to an overreliance on procedural recall rather than conceptual understanding. These challenges point to gaps in pedagogical readiness that may constrain the effective adoption of PBL, which requires teachers to guide learners through open-ended and real-world problem situations. Similarly, Zakaria et al. (2024) note that although mathematics teachers express positive perceptions of integrating mobile learning with problem-based learning, their reflections suggest that meaningful technology integration is closely linked to prior experience, confidence, and alignment with pedagogical intentions. Taken together, these studies indicate that teacher readiness in PBL contexts extends beyond a willingness to adopt innovative approaches and instead involves a deeper understanding of learning design, learner cognition, and instructional coherence.

Professional capacity also emerges as a critical factor influencing how PBL and PjBL are implemented, sustained, and assessed within mathematics education. This capacity encompasses teachers' abilities to design meaningful learning experiences, manage classroom dynamics, scaffold instruction effectively, and align learning activities with intended objectives. Ranmechai & Poonputta (2023) demonstrate that problem-based learning contributes significantly to the development of learning management skills among mathematics education students, particularly in lesson planning and instructional implementation. The high levels of performance and learner satisfaction reported in their study suggest that early exposure to PBL during teacher preparation can strengthen the professional competencies required to manage complex, student-centred learning environments. This finding is consistent with Winarni et al. (2025), who argue that contextual and project-based approaches are essential for improving numeracy instruction and enhancing teaching readiness among prospective teachers. Their analysis of conceptual and procedural errors indicates that professional capacity must also include the ability to identify misconceptions, design meaningful contextual tasks, and employ visual or representational supports appropriately. Within technology-enhanced learning contexts, Zakaria et al. (2024) report that teachers view the integration of mobile learning with problem-based learning as a valuable resource for creative instruction; however, effective implementation depends on teachers' capacity to evaluate technological usability, pedagogical alignment, and instructional relevance. Pham et al. (2025) further emphasise that professional capacity to organise PjBL is empirically distinct from general readiness, underscoring the need for targeted professional development to strengthen competencies related to project planning, facilitation, and evaluation. Collectively, these studies position professional capacity as a dynamic and learnable construct that can be systematically developed through structured PBL experiences in both pre-service and in-service teacher education contexts.

Assessment challenges constitute a third, closely connected dimension within the broader theme of teacher readiness and professional capacity in PBL and PjBL contexts. Evidence from the reviewed abstracts indicates that assessment practices often develop more slowly than instructional innovations, particularly when learning goals emphasise higher-order thinking skills, numeracy literacy, and authentic performance. Jailani et al. (2023) provide detailed insights into the challenges faced by prospective mathematics teachers when designing assessment items targeting higher-order thinking skills (HOTS) within a project-based learning framework. Although PBL was found to enhance participants' understanding of assessment principles, difficulties persisted in aligning cognitive levels, indicators, and item construction, especially in the development of multiple-choice HOTS questions. These findings point to assessment literacy as a critical yet underdeveloped component of teacher readiness in PBL settings. Related findings reported by Setiyani et al. (2024) and Winarni et al. (2025)further suggest that limited familiarity with text-rich and contextualised numeracy tasks constrains both instructional practice and assessment, highlighting the need for teachers to develop proficiency in designing and interpreting assessments aligned with real-world problem-solving. Pham et al. (2025) also indirectly address assessment-related challenges by identifying student characteristics as a significant factor in PjBL implementation, implying that assessment approaches must be responsive to learner diversity and varying levels of readiness. In addition, Ranmechai & Poonputta (2023) demonstrate that the use of holistic rubrics can support the evaluation of learning management skills in PBL environments, offering a viable alternative to conventional assessment methods. Collectively, these studies underscore that assessment challenges in PBL extend beyond technical issues and are deeply intertwined with teacher preparedness, professional capacity, and the alignment of pedagogy, learning outcomes, and evaluation strategies within complex, project-based mathematics learning environments.

Innovation and Design of PBL/PjBL Models

Innovation in PBL and PjBL models is increasingly understood as the deliberate integration of project-based structures with complementary instructional supports that respond to well-documented implementation challenges. Recent studies suggest that effective PBL design extends beyond the use of projects alone, highlighting the need to incorporate regulatory scaffolding, appropriate digital infrastructure, and carefully designed contextual tasks within the overall learning sequence. Such integrated approaches are intended to enhance learner engagement, maintain motivation over extended periods of inquiry, and promote greater instructional coherence across a range of educational contexts. The literature review below is still written from the abstracts' findings and discussion content only, with extensive paraphrasing and a factual tone, and with citations limited to the provided sources. Innovation and design in PBL/PjBL models are frequently described as purposeful blending of project structures with additional supports that solve known weaknesses in conventional implementations. In higher education programming, Gu et al. (2025) report that a combined PBL + self-regulated learning (SRL) design produces stronger intrinsic motivation, higher self-efficacy, and greater course satisfaction than PBL alone or traditional teaching, while also reducing tension and pressure. The design implication is clear: PBL by itself does not guarantee sustained regulation, so model innovation is framed as embedding SRL scaffolds as part of the project sequence, not as optional learner behavior. A second design direction is the integration of Artificial Intelligence to strengthen project planning and implementation quality. Lavado-Anguera et al. (2025) describe AI-supported PBL as a structured approach that can automate repetitive processes, support individualized learning pathways, and improve project management; at the same time, the findings highlight constraints such as limited technology capacity, adaptation difficulties, and training needs, meaning that the design innovation includes teacher-facing structures and ethical guidelines rather than only student tools. At the school level, Nurin et al. (2024) report a design-based research study in which Mobile Math Trails were incorporated within a problem-based learning model to support and reinforce numeracy learning. Findings emphasize that the application's embedded features support problem solving and link mathematical ideas with situated contexts around the school environment; the design also depends on collaboration, active engagement, and physical movement, showing that PBL/PBL-adjacent innovation can be achieved through task architecture and learning ecology, not only through lesson scripts. Taken together, these abstracts suggest that innovative PBL/PjBL designs increasingly function as "bundled" models: project work is combined with regulation scaffolds, digital infrastructure, and context-driven tasks to make intended outcomes more likely (Gu et al., 2025; Lavado-Anguera et al., 2025; Nurin et al., 2024).

A second cluster of innovation focuses on strengthening the internal instructional logic of PBL/PjBL through differentiated materials should be prepared to match numeracy demands. Within the innovation theme, this becomes an argument for designing PBL/PjBL tasks that gradually increase contextual complexity while explicitly training interpretation and representation skills. A complementary materials-design study is provided by Muzakkir et al. (2024) where a Q-STEAM module integrates Quranic approaches with STEAM and emphasizes mathematics within each engineering design process step. Expert validation results show high content validity index values and provide concrete design guidance: contextual problems should appear at the start, triggering questions should activate recall and thinking, and the module structure should follow learner developmental trajectories. These design principles align with scaffolding needs identified by Setiyani et al. (2024) and also echo the structured support logic in Gu et al. (2025) where SRL scaffolding differentiates outcomes beyond PBL alone. When viewed together, the abstracts indicate that innovation is shifting from simply "doing projects" toward engineering sequences of supports: prompts, contextual entry points, developmental ordering, and assessment-sensitive task formats. In that sense, design quality is treated as a measurable attribute of the PBL/PjBL model rather than a general teaching preference, and validated modules or structured scaffolds become mechanisms for reliability across classrooms and cohorts (Setiyani et al., 2024; Muzakkir et al., 2024; Gu et al., 2025).

A broader synthesis is offered through comparative and methodological mapping of student-centered approaches, which helps position current innovations within the larger design landscape and identify missing evidence types. Drobnič Vidic (2023) analyzes 112 high-quality research articles spanning inquiry-based learning, problem-based learning, and project-based learning in mathematics, focusing on interdisciplinary connections, education level, methods, designs, and participants. The findings point to notable differences across approaches and, more importantly, reveal that many experimental studies remain methodologically limited, particularly in terms of the consistent measurement of effect sizes. This mapping suggests that innovation in the design of PBL and PjBL models should be accompanied by stronger evaluative research designs capable of identifying which specific design components contribute to learning outcomes across different contexts. This implication is consistent with the "initial phase" limitation highlighted by Lavado-Anguera et al. (2025), who note that the long-term impacts of AI-enhanced PBL have yet to be established, despite early cycles demonstrating benefits for project management and adaptive support. Similar calls for expansion are evident in Nurin et al. (2024), where Mobile Math Trails–supported PBL is presented as a promising approach for strengthening numeracy, while further studies across diverse learning environments are recommended to examine its generalisability. Along the same lines, Gu et al. (2025) provide quasi-experimental evidence showing that the inclusion of self-regulated learning (SRL) scaffolding leads to changes in learner motivation and satisfaction, indicating that such forms of "hybridisation" can be empirically tested rather than assumed. Across the reviewed abstracts, innovation is therefore not confined to the integration of new technologies or content. Instead, it also involves the explicit specification of design features and the use of evaluative methods that enable meaningful comparison across educational settings. Collectively, these findings point to a future direction for innovation grounded in the combination of design and evidence, whereby structured PBL/PjBL models with clearly articulated components are paired with research designs capable of isolating the contribution of each component within mathematics education contexts (Drobnič Vidic, 2023; Gu et al., n.d.; Lavado-Anguera et al., 2025; Nurin et al., 2024).

CONCLUSION

This systematic literature review synthesised recent empirical research on Project-Based Learning (PBL), also referred to as Project-Based Learning (PjBL), within the context of early mathematics education. Guided by the PRISMA protocol, the review examined peer-reviewed empirical studies published between 2023 and 2025 and indexed in two major academic databases. The review was structured around three primary aims: examining reported learning outcomes of PBL/PjBL for young learners, including mathematics achievement and 21st-century skills; analysing issues related to teacher readiness, professional capacity, and assessment challenges; and identifying innovative design features of PBL/PjBL models relevant to early mathematics settings. By synthesising evidence from 21 primary studies, the review responds to fragmented findings and uneven reporting in the existing literature, offering an integrated perspective on how PBL/PjBL is conceptualised and enacted in early mathematics education.

The synthesis revealed several consistent patterns across the reviewed studies. First, PBL/PjBL approaches were frequently associated with positive learning outcomes, including improvements in conceptual understanding, problem-solving skills, mathematical reasoning, collaboration, creativity, and learner engagement. These outcomes were most evident in learning contexts where tasks were contextualised, product-oriented, and designed to encourage exploration and reflection rather than procedural repetition. Second, teacher-related factors emerged as a critical determinant of effective PBL/PjBL implementation. Teacher readiness was shown to extend beyond positive attitudes to encompass pedagogical knowledge, confidence in facilitating inquiry-based learning, the capacity to organise and manage projects, and competence in aligning assessment practices with higher-order learning objectives. Assessment challenges were particularly prominent, as many studies reported difficulties in designing authentic, performance-based assessments capable of capturing both mathematical understanding and transversal skills. Third, innovation in PBL/PjBL design was characterised by the integration of structured scaffolding, digital tools, and contextual learning environments, as well as hybrid models combining project work with self-regulated or technology-supported guidance. Together, these patterns reflect a shift away from viewing PBL/PjBL as a single instructional method towards understanding it as a flexible and configurable instructional model with interdependent components.

In terms of contribution to the field, this review offers a consolidated thematic framework that integrates learner outcomes, teacher capacity, and instructional design within research on PBL/PjBL in early mathematics education. By organising recent empirical evidence into three interconnected themes, the review extends earlier studies in which these dimensions were often examined in isolation. The findings also hold practical implications for educational practice and policy, particularly in highlighting the importance of sustained professional development, closer curriculum alignment, and assessment reform to support the effective adoption of PBL/PjBL in early mathematics settings.

Despite its systematic scope, several limitations should be acknowledged. The synthesis relied primarily on findings reported at the abstract level, which constrained deeper critical engagement with methodological rigour, reported effect sizes, and contextual nuances across studies. As a result, detailed examination of research designs, sampling adequacy, analytical strategies, and potential threats to validity could not be conducted consistently. In addition, variation in educational levels and instructional settings, including studies situated in secondary, vocational, and higher education contexts, at times diluted the analytical focus on early childhood and early primary mathematics learning. Although clear thematic patterns were identified, comparative depth across studies remained uneven, and contradictory or null findings were not always examined in detail. Furthermore, limited attention could be given to issues of learner diversity, equity, and contextual constraints influencing the effectiveness of PBL, as these factors were inconsistently reported across the reviewed literature.

Future research syntheses would benefit from deeper critical comparison across studies, particularly in examining differences in outcomes across age groups, educational contexts, and specific PBL/PjBL design features. Greater emphasis on methodological limitations, conflicting evidence, and underreported null findings would further strengthen analytical rigour. Additional attention to equity, inclusion, and developmental appropriateness is also needed to clarify when, how, and for whom PBL is most effective in early mathematics education. Moreover, clearer articulation of research gaps—such as the limited exploration of assessment models aligned with PBL and the scarcity of longitudinal evidence on sustained learning impacts—would provide a stronger foundation for future empirical and design-based research. Overall, this review underscores the value of systematic evidence synthesis in advancing understanding of innovative pedagogical approaches in early mathematics education and in supporting informed, evidence-based instructional and policy decisions.

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