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PjBL-STEM Model in Mathematics Education: Systematic Literature Review on Effectiveness, Differentiation, and Affective Dimensions

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Abstract
The changing landscape of 21st-century education demands that mathematics learning is not only oriented towards mastering procedures, but also towards developing higher-order thinking skills, contextual problem-solving, and students' affective engagement. The integration of Project-Based Learning (PjBL) based on Science, Technology, Engineering, and Mathematics (STEM) is seen as a potential pedagogical strategy to address these challenges. Although various studies report the effectiveness of PjBL-STEM on mathematics learning outcomes, studies that comprehensively integrate learning effectiveness, learning differentiation, and students' affective dimensions are still limited. This research aims to systematically examine the application of the STEM-based PjBL model in mathematics education with a focus on learning effectiveness, differentiation practices, and students' affective dimensions. This research uses a Systematic Literature Review approach with reference to the PRISMA guidelines. Articles were collected from Scopus, Web of Science, ScienceDirect, SpringerLink, and ERIC databases from 2015–2025. A total of 12 articles that met the inclusion criteria were analyzed using thematic content analysis and narrative synthesis. The review results show that 10 of the 12 studies reported significant improvements in mathematics learning outcomes, problem-solving abilities, creativity, and 21st-century skills through the implementation of PjBL-STEM. However, only a few studies explicitly integrated learning differentiation strategies, while affective dimensions such as motivation, engagement, and emotional involvement were generally positioned as additional variables. These findings indicate that the implementation of PjBL-STEM needs to be designed more adaptively and inclusively through the integration of learning differentiation and strengthening affective aspects so that all students can be optimally involved in mathematics learning.

INTRODUCTION

The development of 21st-century education demands that mathematics learning be oriented not only toward mastery of concepts and procedures, but also toward the development of higher-order thinking skills (HOTS), contextual problem-solving, collaboration, and student readiness to face real-world challenges. In this context, the Science, Technology, Engineering, and Mathematics (STEM) approach is seen as a relevant integrative framework for bridging mathematics with real-world problems (English, 2016; Li et al., 2020). The STEM approach can also integrate cross-disciplinary concepts through authentic contexts and complex problem-solving.

The STEM approach has the potential to shift the paradigm of mathematics learning from a theoretical to a more applicable and contextual one, thus addressing the need for meaningful learning (Portillo-Blanco et al., 2024). The integration of STEM into mathematics learning enables students to build more meaningful conceptual understanding through authentic problem-solving and project-based activities. One of the most frequently used learning models in STEM implementation is Project-Based

Learning (PjBL). PjBL has a main characteristic that emphasizes authentic and complex project work, where students are actively involved in investigation, collaboration, and problem solving (Chang & Chen, 2022).

The integration of PjBL with STEM (PjBL-STEM) creates a powerful pedagogical synergy, where PjBL provides the pedagogical structure, while STEM provides a rich interdisciplinary context for the projects (Han et al., 2016) and (Li et al., 2020). Several international studies have reported that STEM-based PjBL has a positive impact on mathematics learning outcomes, creative thinking skills, scientific literacy, and 21st-century skills such as collaboration and communication (Han et al., 2016; Lee et al., 2019; Nguyen et al., 2024; Vistara et al., 2022; Kuang et al., 2022). Through contextual and interdisciplinary projects, students are encouraged to construct knowledge, integrate mathematical concepts with science and technology, and develop engineering-based solutions to real-world problems.

However, empirical studies show that the primary focus of PjBL-STEM research is still dominated by cognitive aspects and learning outcomes such as test scores, critical thinking skills, and mathematical creativity. The aspect of learning differentiation has received relatively little attention, even though mathematics classes are generally heterogeneous in terms of students' initial abilities, interests, and learning styles. Differentiated learning in PjBL-STEM has the potential to be a key strategy to ensure that all students are optimally engaged in the same project, but with appropriate support and challenges (Han et al., 2014; Tomlinson, 2017).

Furthermore, affective dimensions such as learning motivation, interest in mathematics, self-efficacy, attitudes toward mathematics, and emotional engagement are often positioned as secondary variables or even ignored in evaluating the effectiveness of STEM-based PjBL. Yet, numerous studies confirm that the success of mathematics learning is strongly influenced by affective factors, which act as mediators between learning design and students' cognitive achievement (Hannula et al., 2016; Lee et al., 2019). PjBL-STEM designed without paying attention to affective aspects and emotional engagement risks not reaching its maximum potential, even though it is conceptually aligned with the principles of active learning.

Several recent systematic reviews indicate a tendency for STEM-based PjBL studies to still not comprehensively integrate analysis of learning effectiveness, differentiation practices, and affective outcomes within a coherent framework, particularly in the context of mathematics education (Cruz et al., 2022; Simamora, 2024). Therefore, a systematic review is needed that critically maps how PjBL-STEM is implemented, the extent to which its effectiveness has been demonstrated, and how differentiation and the affective dimension are positioned within existing research.

Based on the description, this research is directed to answer the following problem formulations: (1) How is the effectiveness of implementing the PjBL-STEM model in mathematics learning in terms of students' cognitive outcomes and 21st-century skills? (2) How is the affective dimension of students positioned in the implementation of the PjBL-STEM model in mathematics learning? (3) How is the practice of learning differentiation integrated in the implementation of the PjBL-STEM model to accommodate the diversity of student characteristics? (4) What is the relationship between cognitive effectiveness, affective dimensions, and learning differentiation in the implementation of the PjBL-STEM model in mathematics education?

This research is novel compared to previous studies, because it not only examines the effectiveness of PjBL-STEM in mathematics learning, but also simultaneously integrates analysis of learning differentiation practices and students' affective dimensions within a single, coherent framework. Thus, this research provides a more comprehensive perspective in understanding how PjBL-STEM can be designed not only cognitively effective, but also inclusive and responsive to student characteristics.

METHODS

This research used a Systematic Literature Review (SLR) approach to comprehensively synthesize research related to the application of the STEM-based Project-Based Learning model in mathematics education. The SLR procedure adheres to the Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) guidelines (Page et al., 2021) to ensure transparency, replicability, and accountability of the literature review process.

The literature search was conducted in five reputable international databases: Scopus, Web of Science, ScienceDirect, SpringerLink, and ERIC, with publications spanning 2015–2025. The search strategy used the following keyword combinations: ("Project-Based Learning OR PjBL") AND ("STEM education") AND ("mathematics education") AND ("affective domain" OR "motivation" OR "engagement") AND ("differentiated instruction" OR "learning differentiation"). The search was limited to articles: (1) in English, (2) published in peer-reviewed journals, and (3) available in full text.

The article selection process followed the PRISMA process, which includes four stages, as shown in Figure 1.

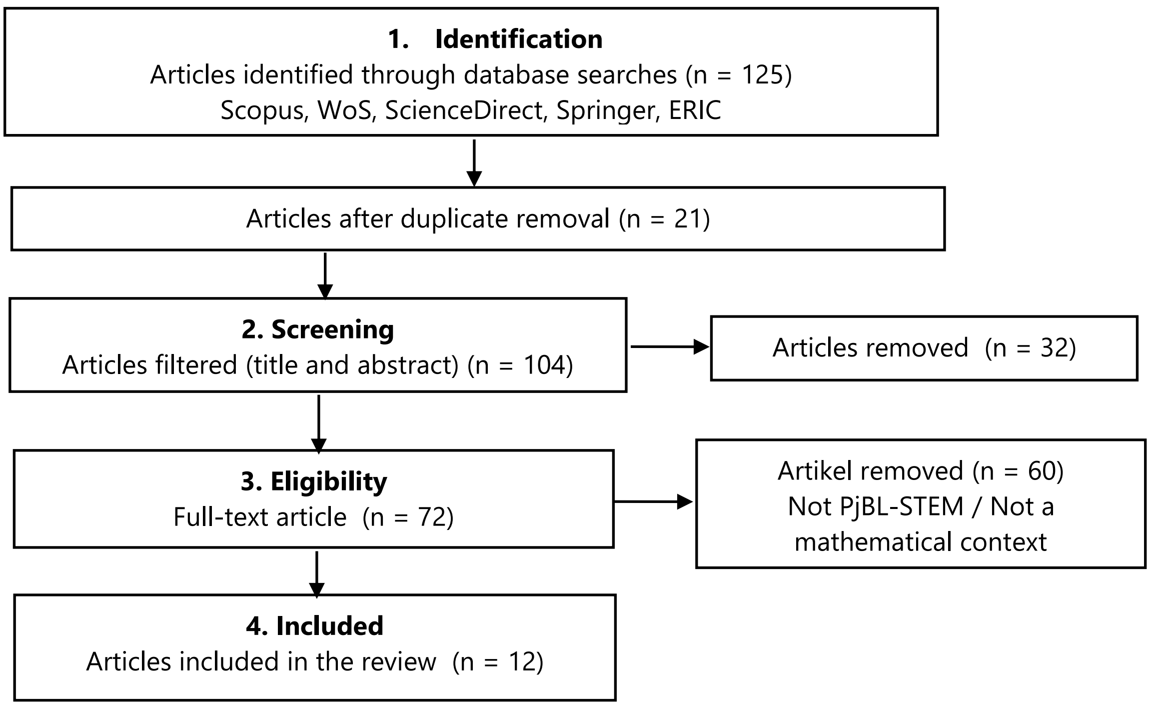

Figure 1. Steps of the PRISMA Method

The 12 articles obtained were selected using the inclusion and exclusion criteria as shown in Table 1.

Table 1. Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
Empirical articles or reviews discussing PjBL-STEM in mathematics education	Purely conceptual articles without empirical data
Published in peer-reviewed international journals	Non-peer-reviewed proceedings
Examines at least one aspect: effectiveness, differentiation, or affective dimension	Not relevant to mathematics education
Year range 2015–2025	Articles outside this year range
Full-text available	Articles not fully accessible

To ensure the methodological quality of the articles analyzed, this research used the Critical Appraisal Skills Programme (CASP) checklist as a study quality assessment tool. Quality assessment was conducted on each article based on several aspects, namely: (1) clarity of research objectives, (2) suitability of research design, (3) characteristics of participants and research context, (4) validity and reliability of research instruments, (5) data collection and analysis procedures, and (6) consistency between research results and conclusions. Each article was assessed to determine its methodological feasibility before being included in the synthesis process. Articles with low methodological quality or not meeting the main assessment indicators were not continued to the analysis stage.

Overall, the selection process yielded 12 articles that met the inclusion criteria for further analysis. The relatively limited number of articles was due to the stringent selection criteria, particularly regarding the focus on the simultaneous integration of PjBL-STEM in mathematics learning, learning effectiveness, differentiation, and the affective dimension.

The data extraction process was carried out systematically using a data extraction form prepared based on the research objectives. Data extraction was carried out in stages for each selected article by recording important information including: (1) research identity (author, year, and country), (2) educational level and number of participants, (3) research design and methods, (4) characteristics of PjBL-STEM implementation, (5) mathematics learning materials or contexts used, (6) indicators of learning effectiveness, such as learning outcomes, critical thinking skills, and problem solving, (7) forms of learning differentiation applied, and (8) affective dimensions studied, such as motivation, learning engagement, interest, and student attitudes towards mathematics.

Data analysis was conducted using thematic content analysis and narrative synthesis because the heterogeneity of research designs and variations in data characteristics between studies did not allow for quantitative meta-analysis. Narrative synthesis was used to identify patterns of findings, trends in PjBL-STEM implementation, and the relationship between learning effectiveness, learning differentiation, and the affective dimension in mathematics education.

RESULTS AND DISCUSSION

The results of the analysis of articles related to the PjBL-STEM model in mathematics learning are as shown in Table 2.

Table 2. Results of the Article Analysis

Kode	Author and Year	Country	Level	Design	Mathematis Topic	STEM Integration	Effectiveness Focus	Cognitive	Affective	Differentiation
S1	(Han et al., 2016)	USA	Senior High School	Quasi-eksperimental	Contextual-Mathematics	Project-integrated STEM	Cognitive	Improved	Not explicit	Implicit
S2	(Prabaningrum & Waluya, 2019)	Indonesia	Junior High School	Quasi-eksperimental	Mathematical Communication	PjBL- STEM	Cognitive	Improved	Not examined	None
S3	(Hakim et al., 2019)	Indonesia	Junior & Senior High School	Descriptive	21st Century Skills	PjBL- STEM	21st skills	Improved	Not examined	None
S4	(Wilson, 2020)	Australia	Junior High School	Qualitative	General	PjBL- STEM	Implementasi	-	Engagement	Implicit

S5	(Wangguway et al., 2020)	Indonesia	Elementary School	Experimental	Arithmatics	STEM-PjBL	Metacognitive	Improved	Not explicit	None
S6	(Sarwi et al., 2021)	Indonesia	Elementary School	Quasi-eksperimental	Problem Solving	PjBL- STEM	Cognitive	Improved	Not examined	None
S7	(Manuel et al., 2021)	Spain	Elementary Teachers	Qualitative	Teacher perspective	STEAM-PjBL	Pedagogical	Not focused	Teacher attitudes	None
S8	(Lee, 2022)	USA	University Student	Qualitative	Elementary mathematics	PjBL- STEM	Affective	Enhanced collaboration and problem solving	Emotional engagement	Role differentiation
S9	(Wan et al., 2022)	Hong Kong	Elementary School	Development	STEM-PjBL experience in mathematics	PjBL- STEM	Affective	-	Motivation & engagement	None
S10	(Coufal, 2022)	Czech Republic	Elementary School	Experimental	Problem Solving	PjBL- STEM	Cognitive	Significant	Motivation (implicit)	None
S11	(Tuong et al., 2023)	Vietnam	Teacher Students	Mixed- &method	Problem solving & 21st Century Skills	Contextual STEM Project	Cognitive	Signifikan	Not examined	Implicit
S12	(Kwon & Lee, 2025)	Multinational	High School - Higher Education	Meta-analysis	Creativity	PjBL- STEM	Affective and HOTS	Effect size sedang-tinggi	Not focused	Not analyzed /discussed

General Characteristics of the Analyzed Articles

Based on an analysis of 12 reputable international articles published between 2015 and 2025, research on STEM-based Project-Based Learning (PjBL) in mathematics education shows a significant upward trend, particularly after 2019. These studies originate from various national contexts, including the United States, Australia, Vietnam, Hong Kong, the Czech Republic, Spain, and Indonesia, demonstrating the global adoption of PjBL-STEM in mathematics education.

In terms of educational level, most research was conducted at the elementary and secondary school levels, with some studies involving teachers and student teachers. The research designs used were predominantly quasi-experimental, followed by qualitative approaches, mixed methods, and one meta-analysis. This methodological variation indicates that PjBL-STEM research is not solely oriented toward measuring the effectiveness of learning outcomes but is also beginning to explore implementation processes, student engagement, and learning experiences.

In general, the synthesis results indicate that PjBL-STEM research is still dominated by a cognitive effectiveness orientation, while affective aspects and learning differentiation have not received much systematic study. This condition indicates a tendency that success in mathematics learning is still measured more by academic achievement than by the quality of students' overall learning experiences.

The Effectiveness of the STEM-Based Project-Based Learning Model in Mathematics Learning

The review results show that the PjBL-STEM model consistently has a positive impact on the effectiveness of mathematics learning at various levels of education, from elementary school to higher education. Most articles used quasi-experimental or experimental designs (S1, S2, S5, S6, S10, S11) and reported significant improvements in students' cognitive outcomes, such as conceptual understanding, problem-solving skills, mathematical communication skills, critical thinking, creativity, and 21st-century skills.

These findings demonstrate that STEM integration in project-based learning can transform mathematics learning from a procedural approach to a more contextual, applicable, and meaningful one. Through authentic projects, students not only learn abstract mathematical concepts but also connect them to real-world problems through investigation, solution design, decision-making, and cross-disciplinary collaboration.

Conceptually, the cognitive effectiveness of PjBL-STEM is influenced by its student-centered learning characteristics. In this model, students play an active role in constructing knowledge through exploration and contextual problem-solving. These activities encourage deeper knowledge construction than conventional learning, which focuses on information transfer. Han et al., (2016) findings show that PjBL-STEM not only improves learning outcomes but also produces significant differences in achievement across student ability groups. Furthermore, Kwon & Lee (2025) meta-analysis shows that PjBL-STEM has a moderate to high effect size on higher-order thinking skills and mathematical creativity. These findings strengthen the argument that PjBL-STEM contributes not only to conceptual mastery but also to the development of complex thinking skills.

However, the synthesis results show that the effectiveness indicators used in research are still diverse and have not been integrated into a comprehensive evaluation framework. Some studies focus on academic test results, while others emphasize 21st-century skills or metacognitive aspects. This variation demonstrates the need for evaluation models that integrate cognitive achievement with affective dimensions and student characteristics.

Learning Differentiation in the Implementation of the PjBL-STEM Model

The review results indicate that learning differentiation is the aspect least explicitly discussed in PjBL-STEM research. Of the 12 studies analyzed, most implemented PjBL-STEM uniformly without systematic differentiation strategies (S2, S3, S5, S6, S9, S10). Learning differentiation, when it appeared in the reviewed studies, was generally implicit, such as through heterogeneous student grouping or assignments within projects (S1, S4, S11), and was not explicitly described as part of a systematically planned pedagogical design.

In fact, the heterogeneous context of mathematics learning demands a learning approach that is responsive to differences in students' initial abilities, interests, and learning styles. Findings by Han et al., (2016) show that the effectiveness of PjBL-STEM differs across high-, medium-, and low-ability student groups. This indicates that without learning differentiation, PjBL-STEM implementation has the potential to create gaps in academic achievement between students. Lee (2022) study is one of the studies that explicitly applies role differentiation in STEM projects. The study showed that assigning roles appropriate to student characteristics can increase emotional engagement, collaboration, and student learning participation more evenly. These findings demonstrate that learning differentiation has the potential to strengthen the effectiveness and inclusiveness of PjBL-STEM.

Thus, learning differentiation can be understood as a supporting factor that enables all students to obtain an equal learning experience in the implementation of PjBL-STEM. Integrating differentiation into project design is crucial so that learning is not only effective for high-ability students but also adaptive to the diversity of student abilities.

Affective Dimension as a Mediator in the Implementation of PjBL-STEM

Analysis of the affective dimension shows that this aspect is still positioned as a secondary variable or even neglected in most PjBL-STEM studies. Of the articles reviewed, only a few studies explicitly examined student motivation, engagement, attitudes, or emotional involvement (S4, S8, S9), while others did not measure the affective dimension or only mentioned it implicitly.

In fact, the synthesis results show that the affective dimension has a strong relationship with students' cognitive success in PjBL-STEM-based mathematics learning. Collaborative, contextual projects encourage students to actively engage in the learning process, thereby increasing curiosity, learning motivation, and emotional engagement during project completion. Lee's (2022) study demonstrated that the implementation of PjBL-STEM enhanced students' collaboration, emotional engagement, and problem-solving skills through role-based projects. Similar findings were reported by Wan et al., (2022), who demonstrated that STEM project-based learning experiences can enhance students' motivation and engagement in mathematics learning.

The results of this synthesis indicate that the affective dimension serves as a mediator between the PjBL-STEM learning design and students' cognitive achievement. The higher the students' emotional engagement and motivation during the learning process, the greater the chance of achieving optimal mathematics learning outcomes. Therefore, the effectiveness of PjBL-STEM is determined not only by the quality of the project or STEM integration, but also by the extent to which the learning is able to create meaningful and engaging learning experiences for students.

However, most studies have not empirically tested this relationship through mediation or moderation models. Therefore, further research is needed to develop a more integrative analytical framework regarding the relationship between affective dimensions and cognitive outcomes in PjBL-STEM implementation.

Conceptual Synthesis of Cognitive-Affective-Differentiation Relationships in PjBL-STEM

Based on a synthesis of all articles, this research found that the effectiveness of PjBL-STEM in mathematics learning is formed through a dynamic relationship between three main components, namely the cognitive dimension, the affective dimension, and learning differentiation. PjBL-STEM provides contextual learning that allows students to engage in authentic investigative, collaborative, and problem-solving activities. These activities encourage increased student engagement, motivation, and emotional involvement during the learning process. The affective dimension then strengthens students' active participation in learning, which ultimately has an impact on improving cognitive abilities such as problem solving, mathematical communication, creativity, and HOTS.

However, the synthesis also shows that the positive impact of PjBL-STEM is not always evenly distributed across all students. Differences in initial abilities and learning characteristics can cause learning effectiveness to vary across student groups. Therefore, learning differentiation is a crucial factor in ensuring that STEM project-based learning can be inclusive and adaptive.

Based on these findings, this research proposes a conceptual framework that:

1) PjBL-STEM serves as the primary learning design;
2) The affective dimension serves as a mediator that strengthens student learning engagement;
3) Learning differentiation serves as a supporting factor for inclusive learning;

4) The interaction of these three aspects contributes to improving students' cognitive outcomes in mathematics learning.

Thus, the effectiveness of PjBL-STEM cannot be understood only from the improvement of academic results, but also from the model's ability to build emotional engagement and accommodate the diversity of student characteristics.

Theoretical Implications

The results of this SLR indicate that PjBL-STEM research in mathematics learning is still dominated by the cognitive effectiveness paradigm. The affective dimension and learning differentiation are still positioned as supporting aspects and have not been systematically integrated into learning design and evaluation.

These findings indicate the need for a shift in research paradigm from merely assessing "whether PjBL-STEM is effective" to "how PjBL-STEM is designed affectively and inclusively for various student characteristics." Therefore, this research proposes the development of a PjBL-STEM conceptual framework that integrates three main components: cognitive effectiveness, affective engagement, and learning differentiation. This framework is expected to serve as the basis for developing mathematics learning models that not only improve students' academic achievement but also support more meaningful, adaptive, and sustainable learning.

CONCLUSION

Based on the SLR results of 12 reputable international articles published between 2015 and 2025, it can be concluded that the PjBL-STEM model consistently demonstrates positive effectiveness in mathematics learning at various levels of education. This model has been proven to improve students' cognitive outcomes, such as conceptual understanding, problem-solving skills, critical thinking, mathematical creativity, and 21st-century skills through authentic projects, contextual learning, and collaborative activities.

The synthesis results show that the effectiveness of PjBL-STEM is not only related to cognitive aspects, but is also influenced by the affective dimension and learning differentiation. Affective dimensions, such as motivation, engagement, and emotional involvement, play a role in strengthening student participation during the learning process. However, the affective aspect and learning differentiation have not been studied systematically, so that PjBL-STEM research in mathematics education is still dominated by a cognitive effectiveness orientation.

This research proposes a conceptual framework for PjBL-STEM that integrates cognitive, affective, and differentiated learning to support more inclusive and adaptive mathematics learning. However, this research is limited by the number of articles reviewed and the predominance of quasi-experimental designs. Therefore, further research is recommended to develop a PjBL-STEM model that integrates differentiated learning strategies and examines the relationship between affective dimensions and cognitive outcomes through longitudinal, mixed-methods, and meta-analytical approaches.

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