

Systematic Review of STEM-Project-based Learning in Science Education: Trends, Project Types, Future Research

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ABSTRACT

This study analyzed 40 Scopus-indexed international journal articles (2016–2025) exploring the defining features of Science, Technology, Engineering, and Mathematics Project Based Learning (STEM-PjBL) in science education, the topics and projects implemented, and recommendations for further research. A systematic literature review following the Preferred Reporting Items for Systematic Reviews and Meta-analyses guidelines was employed as the research methodology. The results showed that quantitative approaches dominated (50%) with a focus on upper secondary and higher education levels. The largest contribution to the research came from Indonesia (35%), followed by the United States (22.5%) and Taiwan (12.5%). Content related to ‘science with other subjects’ was the most prevalent category, accounting for 32.35% of the articles analyzed for science content. The projects implemented were also highly varied, aligning with the research topics. Recommendations include developing samples and methodologies, exploring fields and educational levels, and delving into specific factors. Recommendations are also directed toward policymakers, teachers, students, and schools. Findings confirm that STEM-project-based learning (STEM-PjBL) effectively cultivates critical thinking, fosters creativity, and career interest in STEM fields. Thus, STEM-PjBL emerges as an effective pedagogical strategy in equipping students to tackle the challenges of the 21st century.

KEY WORDS: Project-based learning, science education, STEM education, systematic literature review

INTRODUCTION

The STEM framework constitutes an innovative educational model that integrates science, technology, engineering, and mathematics to equip learners with the competencies required to confront twenty-first century challenges (Petrenko and Kokareva, 2023). By fostering critical thinking, creativity, and problem-solving abilities, the STEM approach seeks to prepare students for entry into an increasingly dynamic workforce (Grigorova, 2022). The interdisciplinary STEM framework facilitates instruction through a range of pedagogical strategies, including question-based learning (Cedillo, 2018) and project-based learning (Capraro et al., 2016; Tseng et al., 2013). Therefore, STEM materials become more meaningful, interactive, and engaging. Furthermore, integrating advanced technologies modernizes both teaching methods and educational materials, thereby transforming complex concepts into more engaging and accessible content for early learners (Grigorova, 2022). Thus, STEM education not only emphasizes multidisciplinary knowledge to solve practical problems but also equips students with much-needed practical competencies and hands-on experience, especially in the ever-growing information technology industry (Derevyanchuk et al., 2024).

Project-based learning (PjBL) is a learner-centered educational model that prioritizes students’ active involvement in creating prototypes, products, or artifacts through comprehensive research activities. Within this framework, learners

independently develop feasible products or present their research findings during their free time, thereby making the learning experience more meaningful (Lou et al., 2017). Teachers can use technology and hands-on project-based tasks to create a modern learning environment that promotes cognitive development, increases motivation to learn, develops collaborative soft skills, and builds technical skills through challenging problem solving (Daineko et al., 2023; Indriyani et al., 2022; Osadchiy and Serezhkina, 2020).

PjBL replaces traditional teaching methods with a student-centered approach. This helps students become better critical thinkers, communicators, and individuals capable of navigating diverse social contexts (Wilhelm et al., 2019). In addition, PjBL is sometimes combined with the STEM method to make STEM-project-based learning (STEM-PjBL). This integration is intended to underscore the importance of using multiple disciplines to solve real-world problems and prepare students for the realities of globalization (Samsudin et al., 2020). Combining the PjBL model with the STEM framework is a new way of teaching that helps students plan their own learning paths and make authentic products that can be used as learning resources (Jauhariyyah et al., 2017).

Beyond curriculum planning, this integration also transforms students into active learners who use different technological tools to turn abstract science and math ideas into engineering applications. This method encourages students to build their own knowledge and uses formative feedback, which is an

important part of the learning process. STEM-PjBL also helps students learn important skills for the 21st century by having them do complicated tasks that require design, problem-solving, and decision-making. This combined approach also makes students more interested in learning, more motivated, and better at critical thinking in a globalized world (Lumbantobing et al., 2022). This method also boosts students' motivation to learn, creativity, and enthusiasm, which makes it easier for them to develop more skills and complete projects successfully (Fatin and Sudira, 2023).

A multitude of systematic literature reviews (SLR) of STEM-PjBL has been produced by several previous researchers. Wahono et al. (2020) provide empirical evidence demonstrating that the incorporation of STEM significantly improves cognitive abilities and academic achievement in Asian pupils. Zhou et al. (2025) illustrate that the intentional integration of the four STEM disciplines results in substantial enhancements in students' academic performance and conceptual comprehension.

Larkin and Lowrie (2023) identified a variety of pedagogical methods that have been effectively implemented in early childhood education, such as exploration-based learning and straightforward tasks that encourage curiosity and interest. In the meantime, McLure et al. (2022) delineate the characteristics of STEM projects in secondary education, emphasizing that these projects are typically interdisciplinary, collaborative, and focused on resolving real-world issues. Megawati (2024) discovered that the integration of STEM-PjBL into the biology curriculum at the tertiary level improves students' laboratory skills and deepens their comprehension of practical work. Meanwhile, Santhosh et al. (2023) emphasized that informal STEM is more effective in fostering interest and knowledge when variables such as duration, community context, and the degree of student engagement are considered.

Furthermore, the implementation of STEM-PjBL in physics education enhances students' conceptual understanding and problem-solving skills while promoting positive attitudes toward science and technology (Roslina et al., 2022). Existing studies indicate that integrating STEM with the PjBL framework yields significant advantages across various learning dimensions, such as motivation, creativity, and both practical and academic skills. Nevertheless, a SLR focused on analyzing recommendations for future research on STEM-PjBL has yet to be conducted.

The findings of this study are expected to provide a comprehensive explanation for stakeholders in the field of science education who will integrate the STEM-PjBL approach into learning practice. The outcomes of this research are also expected to serve as a practical reference for all participants in science education, particularly teachers, lecturers, and researchers, and to provide an alternative pedagogical strategy in this domain. Consequently, investigating the implementation of STEM-PjBL in science education is critically important.

Accordingly, this study functions as a valuable literature resource, pinpointing areas in need of further investigation and highlighting potential challenges to be addressed when applying STEM-PjBL in classrooms and educational institutions.

This study systematically examines forty articles from leading international journals that focus on STEM-PjBL. The publications included in this review span from 2016 to 2025. The investigation is determined around the following research questions:

1. What are the general characteristics of literature discussing the implementation of STEM-PjBL in the context of science education?
2. Which topics and project types are explored within these studies on STEM-PjBL in science education?
3. What are the recommendations for further research that have been synthesized from the existing literature on STEM-PjBL?

METHODOLOGY

A SLR methodology was implemented in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-analyses (PRISMA) guidelines for this investigation (Page et al., 2021). A SLR is a precise approach to the identification, evaluation, and synthesis of all pertinent evidence on a specific subject to address predetermined research inquiries (Carrera-Rivera et al., 2022). Page et al. (2021) regard PRISMA as an evidence-based framework for the effective reporting of systematic reviews and meta-analyses. Therefore, PRISMA was used in this study (Figure 1).

To ensure both relevance and currency, the literature search was confined to publications from 2016 to 2025. Furthermore, only English-language articles were considered to ensure consistency in data extraction and analysis across all reviewed articles. An initial yield of 1088, comprising 951 from the primary database search and 137 from the supplementary search, was retrieved from the Scopus database. These records were then screened and excluded in accordance with the predefined inclusion and exclusion criteria (Table 1).

Based on a search of the Scopus database using the keyword TITLE-ABS-KEY ("STEM Project Based Learning" AND "Science Education") for the years 2016–2025, 1088 documents were retrieved as of March 27, 2026. The data extraction process was guided by a structured form aligned with the research questions and focused on several key elements, including article information, research characteristics, science content, instruments, objectives, results, and recommendations. A summary of the selected journals that contributed to the review is presented in Table 2.

As shown in Table 2, *Jurnal Pendidikan IPA Indonesia* is the journal with the highest frequency, contributing five articles (12.50%) and is indexed in Scopus Q3. *Education Sciences* published four articles (10.00%, Scopus Q1),

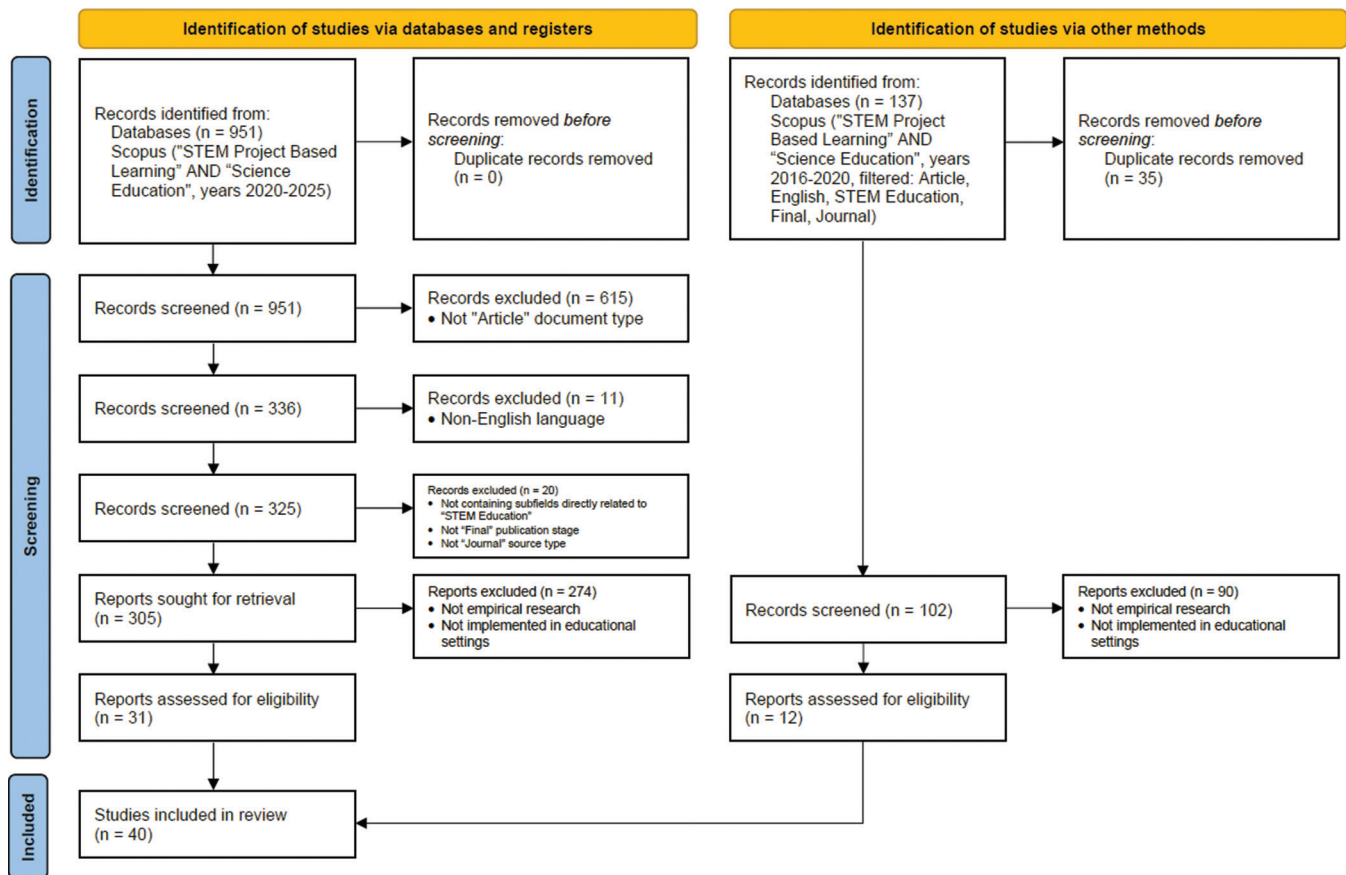


Figure 1: Preferred reporting items for systematic reviews and meta-analyses flowchart illustrating study selection according to inclusion and exclusion criteria

Table 1: Inclusion and exclusion criteria

No	Criteria	Inclusion	Exclusion
1	Database	Articles are from the Scopus database	Article not found in Scopus database
2	Time range	Articles published between 2016 and 2025	Articles published before 2016 or after 2025
3	Document type	Limited to the article	Document types other than "Article"
4	Language	Articles are published in English	Articles published in languages other than English
5	Subject	The article limited to "STEM Education" subject	Not containing subfields directly related to "STEM education"
6	Source type	Articles limited to journal	Source types other than "Journal"
7	Publication stage	Articles limited to final stage	Articles not in "Final" publication stage
8	Publication type	Articles are empirical research (quantitative, qualitative, mixed methods, research and development, or action research)	Non-empirical research articles (books, book chapters, conference papers, literature reviews, editorials, commentaries, theses/dissertations)
9	Implementation setting	STEM-PjBL implemented in educational settings	STEM-PjBL not implemented in educational settings

STEM-PjBL: STEM-project-based learning

followed by the *Eurasia Journal of Mathematics, Science and Technology Education*, the *Journal of Baltic Science Education*, and the *Journal of Technology and Science Education*, each contributing three articles (7.50%, Scopus Q2). The *International Journal of Evaluation and Research in Education* published three articles, accounting for 7.50% of the total, classified in Scopus Q3. The notable representation in esteemed journals (Q1/Q2) and regional publications (Q3/Q4) reflects a broad interest in this subject within academic circles.

This search method demonstrates the growing importance and impact of STEM-PjBL in education.

FINDINGS AND DISCUSSION

This section presents an overview of the findings and discussion derived from a SLR on the implementation of STEM-PjBL in science educational contexts. This analysis addresses three primary research questions, offering insights into the literature's

Table 2: Summary of selected journals for review

No	Name of journal	f	Percentage	Indexed by	H-Index 2024 (SCImagoJournal Rank)
1	Science and education	1	2.50	Scopus (Q1)	142
2	<i>Journal of science education and technology</i>	1	2.50	Scopus (Q1)	85
3	Research in science education	1	2.50	Scopus (Q1)	72
4	Education sciences	4	10.00	Scopus (Q1)	68
5	<i>International Journal of science and mathematics education</i>	2	5.00	Scopus (Q1)	60
6	<i>International journal of technology and design education</i>	1	2.50	Scopus (Q1)	60
7	Research in science and technological education	1	2.50	Scopus (Q1)	43
8	Asia pacific journal of education	1	2.50	Scopus (Q1)	40
9	Interactive technology and smart education	1	2.50	Scopus (Q1)	39
10	<i>European journal of STEM education</i>	1	2.50	Scopus (Q1)	9
11	Frontiers in Psychology	1	2.50	Scopus (Q2)	212
12	<i>Eurasia journal of mathematics, science and technology education</i>	3	7.50	Scopus (Q2)	63
13	Frontiers in education	1	2.50	Scopus (Q2)	55
14	<i>Journal of Baltic Science Education</i>	3	7.50	Scopus (Q2)	29
15	<i>Journal of Turkish Science Education</i>	2	5.00	Scopus (Q2)	27
16	<i>Journal of technology and Science Education</i>	3	7.50	Scopus (Q2)	23
17	Jurnal Pendidikan Ilmu Pengetahuan Alam Indonesia	5	12.50	Scopus (Q3)	30
18	<i>International Journal of Evaluation and Research in Education</i>	3	7.50	Scopus (Q3)	28
19	Interdisciplinary journal of problem-based learning	1	2.50	Scopus (Q3)	26
20	<i>International Journal of Cognitive Research in Science, Engineering, and Education</i>	1	2.50	Scopus (Q3)	17
21	<i>Journal of Education and E-Learning Research</i>	1	2.50	Scopus (Q3)	14
22	<i>Asia Pacific Journal of Educators and Education</i>	1	2.50	Scopus (Q3)	7
23	Jurnal Ilmiah Ilmu Terapan Universitas Jambi	1	2.50	Scopus (Q4)	4
Total		40	100		

general characteristics, the topics and projects examined, and synthesized recommendations for future research.

Research Question 1: What are the General Characteristics of Literature Discussing the Implementation of STEM-PjBL in the Context of Science Education?

To examine the methodological trends in STEM-PjBL research, Table 3 outlines the distribution of research approaches employed in the reviewed studies.

Table 3 shows that quantitative research methods predominate in the evaluated literature, accounting for 50% (20 articles) of all investigations. Qualitative studies comprised 17.50% (7 articles), followed by mixed-method studies at 12.50% (5 articles), research and development at 12.50% (5 articles), and action research at 7.50% (3 articles). The prevalence of quantitative studies suggests a concentration on the evaluation of the efficacy and impact of STEM-PjBL interventions, frequently employing pre-experimental or quasi-experimental designs. This aligns with a broader trend in educational research aimed at providing robust empirical evidence for pedagogical methods (Wahono et al., 2020; Zhou et al., 2025). The distribution of STEM-PjBL investigations across various educational levels was examined by analyzing the characteristics of research participants in order to gain a comprehensive perspective. The reviewed literature included not only students but also teachers and policymakers as

Table 3: Distribution of studies by research methodology

No	Research approach	f	Percentage
1	Quantitative	20	50.00
2	Qualitative	7	17.50
3	Mixed-method	5	12.50
4	Research and development	5	12.50
5	Action research	3	7.50
Total		40	100

research participants. The complete details of this distribution are provided in Table 4.

The data in Table 4 indicate that students represent the predominant participant group in STEM-PjBL research. The peak of participation is at the senior high school and university levels, with both levels accounting for 27.50% (11 articles) of the research analyzed. The lower levels, namely junior high school and elementary school, also received attention with portions of 12.50% and 10.00%, respectively. In addition, teachers and a combination of policymakers also participated, representing 5% of the total. This distribution confirms that STEM-PjBL research spans all educational tiers, though with a markedly stronger focus on secondary and tertiary levels.

Notably, primary school settings remain underrepresented in the literature, a gap that can be attributed to two interrelated factors.

Table 4: Distribution of studies by educational level

Participants/ sample	Educational stage (level)	f	Percentage	Total (%)	E.g., (only first author cited)
Student	Elementary school	4	10.00	36 (90.00)	Wan et al. (2022); Luo et al. (2024); Owens and Hite (2022); Siew and Ambo (2018)
	Middle school	5	12.50		Muzana et al. (2021); Akleman et al. (2019); Mutakinati et al. (2018); Lou et al. (2017); Chen and Lin (2019)
	High school	11	27.50		Martawijaya et al. (2023); Samsudin et al. (2020); Baran et al. (2021); Prajoko et al. (2023); Sulaiman et al. (2023); Sulaiman et al. (2024); Chang and Chen (2022); Purwaningsih et al. (2020); Rahmawati et al. (2021); Sumarni and Kadarwati (2020); Chang and Yen (2023)
	University/undergraduate	11	27.50	2 (5.00)	Badaruddin et al. (2024); Rohman et al. (2024); Nehru et al. (2024); Shidiq et al. (2022); Tsai et al. (2022); Oyewo et al. (2022); Suhartono et al. (2023); Pitot et al. (2024); Sudarmin et al. (2023); Ijirana et al. (2022); Bicer et al. (2025)
	Elementary to high school	1	2.50		Rugh et al. (2021)
	Middle and high school	4	10.00		Jiang et al. (2024); Tsinajinie et al. (2021); Erdogan et al. (2016); Mims et al. (2025)
Teacher	Elementary school	1	2.50	2 (5.00)	Septiadevana and Abdullah (2024)
	Elementary and middle school	1	2.50		Wieselmann et al. (2022)
Others	Policy stakeholder and teacher	1	2.50	2 (5.00)	Wilson (2021)
	Student high school and teacher	1	2.50		Edmunds et al. (2017)
Total		40	100	40 (100)	

From a curriculum design perspective, Larkin and Lowrie (2023) found that STEM projects at the primary level tend to reflect low levels of interdisciplinary integration, as individual disciplines are typically taught through separate curricula with limited institutional effort toward integration, making the transdisciplinary nature of STEM-PjBL difficult to fully realize in these settings. From a student readiness perspective, Wan et al. (2023) noted that cross-disciplinary knowledge application becomes particularly challenging for learners who have yet to develop sufficient foundational understanding within individual subject areas, a limitation more characteristic of primary-level students than their secondary or tertiary counterparts. Together, these factors help explain the observed concentration of STEM-PjBL research at higher educational levels. As illustrated in Figure 2, the deployment of STEM-PjBL in science education spans multiple world regions, including Asia, Africa, North America, Europe, and Australia.

Figure 2 illustrates that STEM-PjBL in science education has been implemented across a diverse set of countries, including Indonesia, the United States, Taiwan, Malaysia, China, Hong Kong, Turkey, Australia, South Africa, and Japan. A detailed breakdown of these national implementations is provided in Table 5.

As shown in Table 5, Indonesia occupies the top position in this study with a contribution of 14 articles (35%), followed by the United States with 9 articles (22.50%) and Taiwan with 5 articles (12.50%). Other countries such as Malaysia, China, Hong Kong, Turkey, Australia, South Africa, and Japan also contributed to the research. This geographic distribution reflects a notable concentration of STEM-PjBL research activity in Indonesia, which may be attributed to the approach's

adaptability to local educational contexts, particularly through local-wisdom and ethno-STEM orientations.

Empirical evidence from the reviewed studies supports this interpretation, demonstrating that ethno-STEM PjBL enhances critical and creative thinking, while broader STEM-PjBL implementations have been shown to improve higher-order thinking, science concept mastery, problem-solving ability, information, communication, and technology (ICT) literacy, and self-efficacy (Martawijaya et al., 2023; Muzana et al., 2021; Purwaningsih et al., 2020; Samsudin et al., 2020; Sumarni and Kadarwati, 2020). These findings suggest that Indonesia's prominence in the literature reflects both sustained research interest and consistent empirical support for STEM-PjBL effectiveness, a pattern further corroborated by Wahono et al. (2020), who documented the broader effectiveness of STEM approaches in improving student learning outcomes across Asian contexts. The publications reviewed span the period from 2016 to 2025, as detailed in Figure 3.

Figure 3 illustrates a substantial rise in the volume of publications from 2016 to 2025. Publications peaked in 2022 and 2024 with eight pieces, and the lowest count was in 2016 with one item. This phenomenon shows high global enthusiasm for research involving the STEM-PjBL interdisciplinary approach. This pattern corroborates Wahono et al. (2020)'s observation of a growing adoption of STEM-PjBL in education contexts driven by the demands for 21st century skills.

Research Question 2: Which Topics and Project Types are Explored within these Studies on STEM-PjBL in Science Education?

In this review, science content is categorized into six domains: Science, Physics, Chemistry, Biology, Science Integration, and

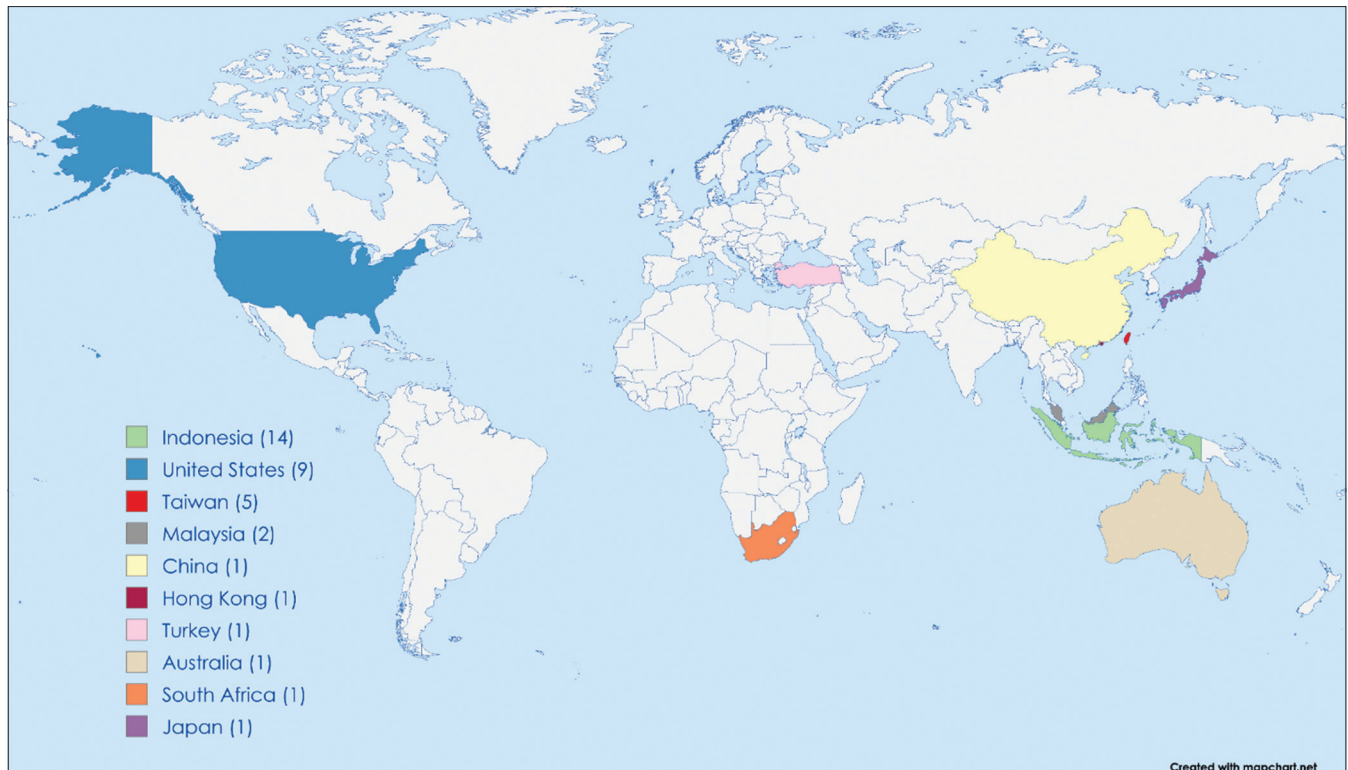


Figure 2: Geographic distribution of STEM-PjBL implementation in science education

Table 5: The distribution of research based on the countries that implement STEM-PjBL in science education

No	Country	f	Percentage	E.g.
1	Indonesia	14	35.00	Martawijaya et al. (2023); Prajoko et al. (2023); Badaruddin et al. (2024); Rohman et al. (2024); Nehru et al. (2024); Shidiq et al. (2022); Muzana et al. (2021); Purwaningsih et al. (2020); Rahmawati et al. (2021); Suhartono et al. (2023); Septiadevana and Abdullah (2024); Sudarmin et al. (2023); Sumarni and Kadarwati (2020); Ijirana et al. (2022)
2	United States	9	22.50	Wieselmann et al. (2022); Pitot et al. (2024); Tsinajinie et al. (2021); Rugh et al. (2021); Akleman et al. (2019); Edmunds et al. (2017); Erdogan et al. (2016); Bicer et al. (2025); Mims et al. (2025)
3	Taiwan	5	12.50	Chang and Chen (2022); Tsai et al. (2022); Chang and Yen (2023); Lou et al. (2017); Chen and Lin (2019)
4	Malaysia	2	5.00	Samsudin et al. (2020); Siew and Ambo (2018)
5	China	1	2.50	Jiang et al. (2024)
6	Hong Kong	1	2.50	Wan et al. (2022)
7	Turkey	1	2.50	Baran et al. (2021)
8	Australia	1	2.50	Wilson (2021)
9	South Africa	1	2.50	Oyewo et al. (2022)
10	Japan	1	2.50	Mutakinati et al. (2018)
Others				
11	South Korea and Malaysia	2	5.00	Sulaiman et al. (2023); Sulaiman et al. (2024)
12	China and Hong Kong	1	2.50	Luo et al. (2024)
13	China, France, and the United States	1	2.50	Owens and Hite (2022)
Total		40	100	

Science with Other Subjects. Articles classified under “science integration” and “science with other subjects” were specifically selected to explore interdisciplinary applications of scientific topics. Detailed distributions are presented in Table 6.

As shown in Table 6, it can be seen that the content of science with other subjects is the most frequently discussed content, which is 32.35% (11 articles), followed by physics content 20.59% (7 articles) and science and chemistry content each 17.65%

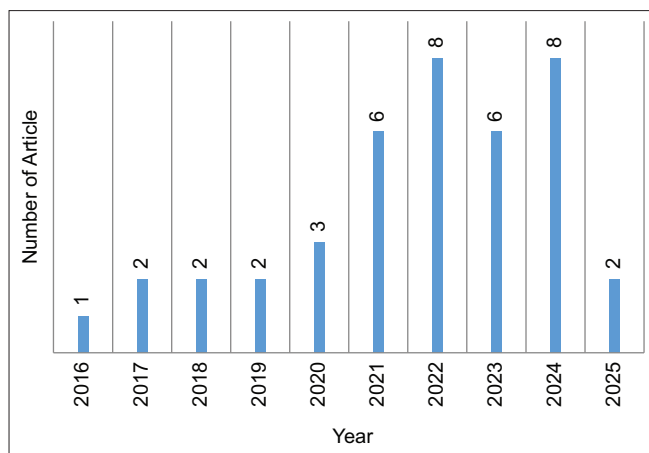


Figure 3: Annual distribution of reviewed publications

Table 6: The distribution of research based on the science content

Science content	Information	f	Percentage
Science	-	6	17.65
Physics	-	7	20.59
Chemistry	-	6	17.65
Biology	-	2	5.88
Integrated science with other subjects	Physics, Chemistry, and Engineering	1	2.94
	Physics, Chemistry, and Mathematics	1	2.94
	Science and Mathematics	3	8.82
	Physics, Mathematics, and Robotics	1	2.94
	Science and technology	1	2.94
	STEM	6	17.65
Total		34	100

(6 articles). In addition, biology content accounted for 5.88% (2 articles), while integrated science comprised a similar proportion at 5.88% (2 articles). These findings underscore a pronounced focus on both interdisciplinary science applications and physics-based concepts within STEM-PjBL initiatives. It is worth noting that six of the forty reviewed articles did not explicitly describe the projects implemented, and therefore only 34 articles were included in the science content analysis presented in Table 6. A comprehensive overview of project data and science-related topics is provided in Table 7.

Table 7 presents six STEM-PjBL projects undertaken within the science domain. Projects in this science category generally focus on the development of learning media, such as the creation of a science encyclopedia (Badaruddin et al., 2024), the use of water hyacinth plants for environmental physics studies (Rohman et al., 2024), and the development of educational games for elementary school students (Tsai et al., 2022). Several studies also focus on the creation of learning modules, such as the topics of the human body organ system and changes in matter (Septiadevana and Abdullah, 2024). Project data and topics discussed in physics can be seen in Table 8.

Table 8 shows that physics projects generally focus on the concepts of mechanics and fluids. For example, students design miniature houses or boats to study gravity and buoyancy (Martawijaya et al., 2023) and build cranes or pulleys (Samsudin et al., 2020). In addition, there are egg drop projects and spaghetti bridge construction (Sulaiman et al., 2023; Sulaiman et al., 2024), water rocket construction (Purwaningsih et al., 2020), and simple laser construction (Suhartono et al., 2023). All of these projects emphasize the practical application of physics principles. Project specifications and topic areas related to chemistry are detailed in Table 9.

As shown in Table 9, chemistry projects emphasize practical applications and material characteristics. For example, Shidiq et al. (2022) designed and built a simple atomic absorption spectrophotometer, while Oyewo et al. (2022) processed water using agricultural waste. Rahmawati et al. (2021) developed biodegradable plastic, and Sumarni and Kadarwati (2020) produced soy tofu. In addition, several studies involve designing chemical structures for batik practice (Sudarmin et al., 2023) and developing learning instruments for analytical chemistry (Ijirana et al., 2022). Project details and biology-related topics are presented in Table 10.

Table 10 shows that, although limited in number, biology projects focus on developing solutions related to human locomotion systems and synthetic biology. Examples include the creation of a mind map of the human motion system (Prajoko et al., 2023) and the design of synthetic biology solutions using a “design-build-test-learn” stage (Mims et al., 2025). Table 11 presents the project data and thematic areas addressed within integrated science.

As shown in Table 11, it can be seen that the projects combine various scientific disciplines to address complex challenges, such as the design of a wastewater treatment system (Mutakinati et al., 2018) and the development of a CaC₂ steamer (Lou et al., 2017). Table 12 summarizes the projects and topics that bridge science with other subjects.

As shown in Table 12, it can be observed that this category illustrates the transdisciplinary nature of STEM-PjBL by integrating mathematics, robotics, and environmental studies. Some projects include the development of an integrated project-based STEM framework for pre-service teachers (Pitot et al., 2024), the design of engineering prototypes such as parachutes, balloon cars, and drones (Bicer et al., 2025), and build a sailboat robot (Chang and Chen, 2022). Several initiatives focus on environmental issues, such as air pollution (Owens and Hite, 2022), solid waste recycling (Akleman et al., 2019), and sustainable agriculture (Wieselmann et al., 2022). The application of microcontroller technology and green energy solutions also stand out (Chen and Lin, 2019).

Research Question 3: What are the Recommendations for Further Research that have been Synthesized from the Existing Literature on STEM-PjBL?

As a guide for further research directions, Table 13 presents

Table 7: Science-related project themes and topics

No	Topic	Project	E.g., (only first author cited)
1	Materials and their properties and changes Simple flat plane Sound energy Simple electricity Plants and their environment Anatomy and physiology of the human body	Creating a science encyclopedia	Badaruddin et al. (2024)
2	Environmental physics	Utilization of water hyacinth plants	Rohman et al. (2024)
3	Energy	Educational Games for Elementary Students	Tsai et al. (2022)
4	The topic is not explained	Sky island ecology, earth sciences, chemistry, hydrology, and astronomy	Tsinajinie et al. (2021)
5	Organ systems of the human body Substances and their changes	Create student learning modules	Septiadevana and Abdullah (2024)
6	The topic is not explained	Create modules with themes such as Animal of my Imagination, Bird Cage, Floating Seeds, Balloon-Powered cars, Light-Friendly house, dan Mini Ice Box	Siew and Ambo (2018)

Table 8: Physics-related project themes and topics

No	Topic	Project	E.g., (only first author cited)
1	- Gravity, buoyancy, and balance - Buoyancy and velocity - Elasticity and Hooke's law - Mechanical advantage concept - Archimedes principle - Light reflection - Heating and evaporation - Capillarity	- Miniature houses/Floating boats and support boats - Miniature motorboats and sailboats - Fish slingshot - Pulley on a conical net - Fish traps - Zinc/Roof - Drinking water distillation - Traditional lamps	Martawijaya et al. (2023)
2	Mechanics	Create the design and construction of a crane/pulley system capable of lifting metallic pieces or heavy boxes	Samsudin et al. (2020)
3	Mechanics	- Egg drop project (create a protective container that can prevent eggs from breaking when dropped from a certain height) - Spaghetti bridge project (building a simple bridge model based on dried spaghetti)	Sulaiman et al. (2023); Sulaiman et al. (2024)
4	Dynamics rotation	Create analysis reports and presentations	Nehru et al. (2024)
5	Momentum and impulse	Making a water rocket	Purwaningsih et al. (2020)
6	Electricity, monochromatic wavelength, and light intensity	A simple laser that focuses on monochromatic light	Suhartono et al. (2023)
7	Rotational motion	Creating spinners that can compete in 5 categories	Rugh et al. (2021)

Table 9: Chemistry-related project themes and topics

No	Topic	Project	E.g., (only first author cited)
1	Chemical separation and measurement practicum	Simple atomic absorption spectrophotometer (AAS)	Shidiq et al. (2022)
2	The topic is not explained	Water treatment using agricultural waste materials (banana peels and orange peels)	Oyewo et al. (2022)
3	Polymer	Making biodegradable plastic	Rahmawati et al. (2021)
4	Secondary metabolites	Designing chemical structure motifs of secondary metabolites and subsequently employing batik techniques on canvas	Sudarmin et al. (2023)
5	Colloids	Producing soybean tofu using a simple technology that has been used by tofu artisans	Sumarni and Kadarwati (2020)
6	- Chemistry learning development (P3K) - The basics of analytical chemistry (DDKA)	- High school learning instruments in the form of documents of lesson plans, worksheets, teaching materials, learning media, and assessment instruments. - Designing, implementing, and reporting of experimental data from flame tests, cation and anion assays, as well as preservative and dye experiments using materials sourced from the surrounding environment	Ijirana et al. (2022)

a summary of recommendations identified from the data analysis. Each recommendation is categorized based on its research focus and is accompanied by references to studies that address similar aspects.

Table 10: Biology-related project themes and topics

No	Topic	Project	E.g., (only first author cited)
1	Human motion system	A Mindmap of the Human System of Motion	Prajoko et al. (2023)
2	Synthetic biology	Designing synthetic biology solutions using the “design-build-test-learn” stage	Mims et al. (2025)

Table 11: Integrated-science project themes and topics

No	Topic	Project	E.g., (only first author cited)
1	Colloid, solution, suspension, and wastewater	Designing a wastewater treatment system	Mutakinati et al. (2018)
2	The principles of buoyancy, density, fluid, thermal energy, heat transfer, and Newton’s laws of motion	Designing CaC ₂ steamship	Lou et al. (2017)

As shown in Table 13, thirteen of the reviewed studies recommended expanding sample size to increase the generalizability of findings. Furthermore, 17 studies emphasized the importance of strengthening experimental designs through consistent iterative testing and the inclusion of control groups. In addition, researchers recommend expanding the disciplinary scope (9 articles) and implementing longitudinal research designs (5 articles) to assess the enduring impact of STEM-PjBL on student outcomes. It should be noted that a single article may contribute more than one recommendation, meaning the total frequency across categories may exceed the number of reviewed articles.

In terms of competency development, future research should place greater emphasis on the 21st-century skills most central to the STEM-PjBL framework, including critical and creative thinking, problem solving, communication, collaboration, and ICT/digital literacy. While the existing literature consistently points to STEM-PjBL’s positive contributions to thinking skills, creativity, problem-solving ability, self-efficacy, ICT literacy, and scientific identity, there remains a need to move beyond broad effectiveness claims. Specifically, researchers recommend more nuanced investigations into how these competencies are cultivated across diverse learner profiles, instructional contexts, and inclusive design

Table 12: Science and other-subject project themes and topics

No	Topic	Project	E.g., (only first author cited)
1	Water waste, sustainable farming, climate change, recycling effort, and viruses	Establish an integrated project-based STEM framework (PBL)	Pitot et al. (2024)
2	- Algebra 2 - Earth and environmental science	- Propose to sell 3 products to the Small Business Administration - Creating public service advertisements related to natural disasters	Edmunds et al. (2017)
3	The topic is not explained	Designing parachute, balloon cars, catapults, trebuchets, bridge structures, paper engineering, cryptography, 3D printing and Tinkercad design, city building, drone design, and speaker design	Bicer et al. (2025)
4	Hull structure, principles of sailboat navigation, basic structure and components of a robot, principles of robot motion	Creating a sailboat robot that can move on the surface of the water and follow a route	Chang and Chen (2022)
5	Air pollution	Designing the water cycle model and how it can interact with air pollution	Owens and Hite (2022)
6	Solid waste materials	Hydraulic robot hand, Hydraulic bridge, Drilling Machine, Balloon car, Small electric engine, Popcorn machine, Magnet engine, Parachute, Torch, Rocket, Solar panel, Periscope, Telescope, Lift, Toy copter, Thermos, Endless waterfall	Baran et al. (2021)
7	Fresh fruits and vegetables, prairie ecosystem, flooding, water quality, catastrophic event, chemical hazards, gentrification, and environmental injustice	Designing a container garden, make information boards and lane signs, presenting a website to city council members, write and present proposals and filtration models, presenting a media campaign, making a booth, making documentaries that challenge the status quo of environmental injustice, drafting a joint memo	Wieselmann et al. (2022)
8	The technology behind vehicles, pandemic, and other topics are not explained	Create a Mars Rover vehicle design, investigating the scientific and social implications of a pandemic, make a rollercoaster to your specifications, creating a habitable Minecraft world for exoplanets	Wilson (2021)
9	Plastic waste	Recycling plastic waste	Akleman et al. (2019)
10	The topic is not explained	Developing of a water-tower prototype using truss tower structure that can withstand earthquakes	Chang and Yen (2023)
11	Simple machines, density concept, fluid, thermodynamic, conservation of mechanical energy, Newton’s laws of motion	- Combining GigoToys and Arduino microcontrollers - Generating electricity from green energy	Chen and Lin (2019)

Table 13: Recommendations for further research

No	Recommendations	Criteria	E.g., (only first author cited)	f
1	Developing research samples and methodology	Diversification of research samples	Martawijaya et al. (2023); Samsudin et al. (2020); Baran et al. (2021); Badaruddin et al. (2024); Chang and Chen (2022); Wilson (2021); Tsai et al. (2022); Pitot et al. (2024); Luo et al. (2024); Rugh et al. (2021); Chang and Yen (2023); Lou (2017); Bicer et al. (2025)	13
		Experimental design improvements	Badaruddin et al. (2024); Nehru et al. (2024); Shidiq et al. (2022); Chang and Chen (2022); Wieselmann et al. (2022); Jiang et al. (2024); Purwaningsih et al. (2020); Wan et al. (2022); Tsai et al. (2022); Suhartono et al. (2023); Pitot et al. (2024); Tsinajinie et al. (2021); Septiadevana and Abdullah (2024); Owens and Hite (2022); Akleman et al. (2019); Chang and Yen (2023); Mims et al. (2025)	17
2	Exploring fields and levels of education	Diversification of disciplines	Samsudin et al. (2020); Badaruddin et al. (2024); Rohman et al. (2024); Chang and Chen (2022); Wan et al. (2022); Pitot et al. (2024); Septiadevana and Abdullah (2024); Sudarmin et al. (2023); Lou et al. (2017)	9
		Long-term research	Wieselmann et al. (2022); Suhartono et al. (2023); Sumarni and Kadarwati (2020); Rugh et al. (2021); Mims et al. (2025)	5
3	Conduct research for specific factors	Thinking skills analysis	Nehru et al. (2024); Jiang et al. (2024); Purwaningsih et al. (2020); Owens and Hite (2022); Sumarni and Kadarwati (2020); Ijirana et al. (2022); Akleman et al. (2019)	7
		Inclusivity research	Tsinajinie et al. (2021); Akleman et al. (2019); Mims et al. (2025)	3
Total				54

Table 14: Recommendations in learning

No.	Recommendations	Criteria	E.g., (only first author cited)	f
1	Policy makers	Infrastructure and policy development	Baran et al. (2021)	1
2	Teacher	Stakeholder support	Sulaiman et al. (2023); Sulaiman et al. (2024)	2
		Professional development	Sulaiman et al. (2023); Septiadevana and Abdullah (2024); Chen and Lin (2019)	3
3	Student	Learning strategies	Muzana et al. (2021); Tsai et al. (2022)	2
		Increased engagement	Edmunds et al. (2017)	1
4	School	Special support	Chang and Yen (2023); Siew and Ambo (2018)	2
		Curriculum and module development	Sulaiman et al. (2023); Sulaiman et al. (2024); Chang and Chen (2022); Septiadevana and Abdullah (2024); Siew and Ambo (2018); Bicer et al. (2025); Chen and Lin (2019)	7
		Innovative learning strategies	Prajoko et al. (2023); Oyewo et al. (2022); Luo et al. (2024); Sumarni and Kadarwati (2020); Ijirana et al. (2022); Rugh et al. (2021); Akleman et al. (2019); Lou et al. (2017); Chen and Lin (2019)	9
		Implementation and evaluation	Jiang et al. (2024); Pitot et al. (2024); Akleman et al. (2019); Mutakinati et al. (2018); Siew and Ambo (2018); Edmunds et al. (2017); Erdogan et al. (2016)	7
Total				34

considerations. Deepening this analysis would provide a more thorough understanding of the cognitive mechanisms underlying STEM-PjBL and strengthen its applicability across varied educational settings. As a guide for continuous improvement in learning practices, Table 14 presents targeted recommendations organized according to the roles of key stakeholders.

As detailed in Table 14, recommendations in learning underscore the necessity of developing both infrastructure and policy frameworks to support STEM-PjBL implementation and fostering active stakeholder engagement. In addition, it is recommended that educators' professionalism be strengthened through targeted training and the adoption of innovative learning strategies to support effective STEM-PjBL implementation. From the learner's perspective, efforts

to increase engagement and providing special support are identified as key factors in maximizing the benefits of PjBL. Schools are likewise encouraged to develop curricula and learning modules, design innovative learning strategies, and ensure continuous evaluation and improvement. The STEM-PjBL research stream map based on science content, year of publication, level of education that is the object of study, and participant group is presented in Figure 4.

Figure 4 shows that majority of the physics studies were published between 2020 and 2024, with high school being the most researched level of education, followed by universities. Meanwhile, in chemistry, the distribution of articles was fairly even from 2020 to 2023, with a major focus also on high school and university levels. In 2017–2019, the number of scientific articles was relatively limited and focused on

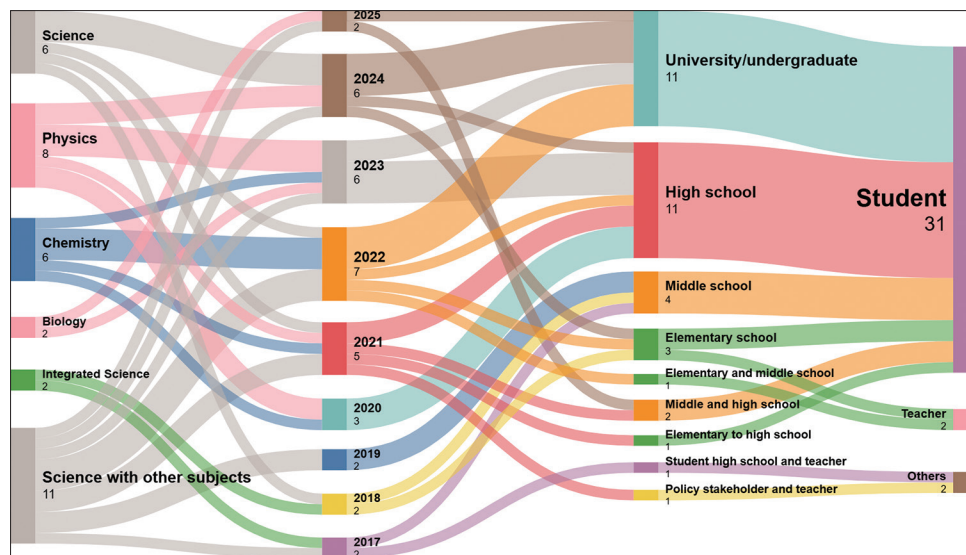


Figure 4: Distribution of STEM-project-based learning by science content, year of publication, education level, and participant group

elementary and junior high school levels. Entering 2021, the distribution of research became broader, covering almost all levels of education. However, in the period 2022–2025, attention again focused on two main levels: Undergraduate level at universities and high school. These trends reflect a selective focus on topics aligned with the complexity of the content and students’ readiness at each educational level, alongside periodic increases in publication volume driven by specific themes emphasized in certain years.

The literature synthesis demonstrates that STEM-PjBL significantly enhances twenty-first-century competencies, such as critical thinking skills (Sumarni and Kadarwati, 2020; Ijirana et al., 2022; Oyewo et al., 2022; Nehru et al., 2024) and creativity (Lou et al., 2017; Siew and Ambo, 2018; Prajoko et al., 2023; Rohman et al., 2024; Kwon and Lee, 2025). This outcome corroborates the meta-analysis of Zhou et al. (2025), indicating that STEM integration can improve academic performance, with an effect size of 0.661. In addition, STEM-PjBL encounters can serve as effective instruments for influencing students’ scientific identity, facilitating their self-recognition in the field of science and encouraging them to seek jobs in this domain (Jiang et al., 2024).

Moreover, the integration of STEM with PjBL enhances students’ comprehension of physics concepts (Martawijaya et al., 2023), strengthens self-efficacy in solving physics problems (Samsudin et al., 2020), and increases interest in STEM careers (Rugh et al., 2021). Megawati (2024) also emphasized the enhancement of biology practical skills in higher education through STEM-PjBL. Badaruddin et al. (2024) indicated that STEM-PjBL improves scientific literacy in pre-service elementary educators. Likewise, Purwaningsih et al. (2020) and Muzana et al. (2021) evidenced its efficacy in enhancing students’ problem-solving abilities and ICT literacy. These findings indicate that STEM-PjBL is an efficacious teaching approach for augmenting students’ 21st century competencies.

CONCLUSION

This systematic review of forty STEM-PjBL studies confirms that the approach effectively develops the competencies students need for the 21st century. In terms of research methodology, quantitative approaches are the most prevalent, accounting for 50% of the total studies. Research is primarily focused on senior high school and university levels, with each level accounting for 27.50% of the total studies. Geographically, Indonesia ranks first in research contributions with 35% of the total articles, followed by the United States and Taiwan.

Science content analysis shows that the category “science with other subjects” dominates with 32.35% of the total articles. The implemented projects show diversity. In the general science field, projects focus on the development of learning media. Physics projects generally emphasize concepts of mechanics and fluids. Chemistry projects emphasize practical applications and material characteristics. Although limited, biology projects focus on human motion systems and synthetic biology. Integrated science projects combine multiple disciplines to address complex challenges. The science with other subjects category illustrates the transdisciplinary nature of STEM-PjBL by integrating mathematics, robotics, and environmental studies.

Several essential recommendations for future study were identified from the literature synthesis. Recommendations encompass developing samples and methodologies, exploring fields and educational levels, and delving into specific factors. From a learning perspective, recommendations are aimed at policymakers, teachers, students, and schools.

Further research is recommended to conduct an in-depth analysis of the STEM-PjBL instructional sequence to understand the most effective sequence and structure of learning steps, comprehensively evaluate the benefits of implementing the STEM-PjBL model for learners, and conduct a literature review that includes articles in languages other than

English, so that it can capture findings and best practices from a broader global context.

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