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IMPLEMENTATION OF PROJECT-BASED LEARNING IN STEM EDUCATION

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Abstract

This study aims to assess the effectiveness of project-based learning (PjBL) implementation in STEM education through a literature review at various levels of education in Indonesia. The method used is a systematic literature review of scientific articles, both national and international. The results of the study indicate that the integration of PjBL-STEM consistently improves learning outcomes, science literacy, and 21st-century skills such as critical thinking, creativity, collaboration, and communication. The main supporting factors for successful implementation include institutional support, teacher competence, student motivation, and adequate learning facilities. Meanwhile, the obstacles encountered include limited facilities, lack of teacher training, and challenges in integrating STEM across disciplines. Overall, the implementation of PjBL-STEM is highly recommended as an innovative learning strategy that is relevant to prepare students to face global challenges in the era of the industrial revolution 4.0.
Keywords: Implementation, Project-Based Learning, STEM Education.

Introduction

Twenty-first century education requires a paradigm shift in the learning process, particularly in preparing a generation capable of facing global challenges. One of the main challenges is the need for human resources with critical thinking, creative, collaborative, and communicative skills (Judijanto & Aslan, 2025); (Purike & Aslan, 2025).

These skills are highly relevant to learning approaches that emphasise the integration of science, technology, engineering, and mathematics, known as STEM. The integration of STEM education into the national curriculum has become a major concern in various countries, including Indonesia. This is driven by rapid technological developments and increasingly complex workplace requirements. STEM education is believed to produce graduates who are adaptive, innovative, and ready to compete in the era of the 4.0 industrial revolution. However, the implementation of STEM education requires effective learning strategies that are relevant to the needs of students (Hanif et al., 2021). One approach that is considered effective in the implementation of STEM education is project-based learning (PjBL).

PjBL provides students with the opportunity to develop knowledge and skills through direct experience in completing contextual and meaningful projects. Through PjBL, students not only understand concepts theoretically but also apply them in real-life situations (Simamora, 2022); (Widjaja & Aslan, 2022).

Various studies indicate that the application of PjBL in STEM education can improve learning outcomes, science literacy, and critical and creative thinking skills among students. Studies at the primary to secondary school levels show significant improvements in cognitive, affective, and psychomotor aspects of students after participating in project-based learning integrated with STEM (Li & Wang, 2020).

In addition, PjBL also encourages collaboration and communication among students, thereby building teamwork and shared responsibility. The learning process becomes more active and participatory, as students are directly involved in the planning, implementation, and evaluation of projects. This is in line with the objectives of STEM education, which emphasises creative and innovative problem solving. However, the implementation of PjBL in STEM education is not without challenges. Some of the obstacles often encountered include limited laboratory facilities, lack of teacher training in designing relevant projects, and high administrative burdens. In addition, assessment of project-based learning outcomes requires a special approach in order to evaluate the process and products objectively (Simamora, 2024).

Nevertheless, various efforts have been made to overcome these obstacles, such as the development of learning modules, teacher training, and the use of digital technology in project implementation. Support from various parties, including the government, schools, and the community, is essential to create a conducive and sustainable STEM learning ecosystem (Firmansyah & Aslan, 2025a); (Firmansyah & Aslan, 2025b).

This literature review aims to analyse the implementation of project-based learning in STEM education based on the results of studies conducted in Indonesia. The focus of the study includes the effectiveness of PjBL-STEM in improving learning outcomes and 21st-century skills, as well as the supporting and hindering factors of implementation. It is hoped that the results of this study can contribute to the development of learning practices in schools, particularly in efforts to improve the quality of STEM education through a project-based approach.

Research Method

The research method used was a Systematic Literature Review (SLR), which involved collecting, selecting, and analysing relevant scientific articles related to the implementation of project-based learning in STEM education at various levels of education in Indonesia. The literature search was conducted through online databases such as Google Scholar, ERIC, and Garuda. Articles that met the criteria were then analysed qualitatively using a thematic approach to identify trends, effectiveness, challenges, and recommendations for the implementation of PjBL-STEM, and to ensure transparency and systematicity in the literature review process (Torraco, 2016); (Bolderston, 2008).

Results and Discussion

Effectiveness of PjBL-STEM Implementation in Various Levels of Education

The effectiveness of integrated STEM Project-Based Learning (PjBL) has been widely studied at various levels of education, from elementary to high school. In general, research results show that this model is able to significantly improve learning outcomes, critical thinking skills, creativity, science literacy, and collaboration skills of students at various levels of education (Hanif et al., 2021).

At the primary school level, the implementation of PjBL-STEM has proven effective in improving cognitive abilities, creativity, understanding of science concepts, and scientific process skills. Data from several journals indicate that this model can significantly improve learning outcomes and critical thinking skills compared to conventional learning models. One study reported that the experimental group using PjBL-STEM achieved higher average scores than the control group, with a 7.51% increase in critical thinking skills (Auliyani et al., 2025).

Beyond cognitive aspects, PjBL-STEM also has a positive impact on primary school students' science literacy. Research demonstrates that students learning through this model show significant improvements in science literacy scores, both in pre-test and post-test results. Hypothesis testing revealed significant values supporting the effectiveness of this model in enhancing science literacy compared to other learning models (Hidayati et al., 2023).

At the junior high school level, the implementation of PjBL-STEM also shows positive results. Experimental research indicates an increase in science learning outcomes among students with an N-gain of 42.48% in the PjBL-STEM group, compared to 21.22% in the discovery learning-scientific group. In addition, students' collaboration skills also increased to 80%, with students' responses to this model being very positive (Christopoulos et al., 2020).

At the senior high school level, the PjBL-STEM model was effective in improving mathematics and science learning outcomes. The average post-test scores of students who participated in integrated STEM project-based learning were above the Minimum Passing Criteria (KKM), with normalised gains in the high category and classical mastery reaching over 80%. Student activities during learning were also active, and their responses to this model were very positive (Markula & Aksela, 2022).

The implementation of PjBL-STEM also contributed to developing creative problem-solving skills, metacognition, and technological and ICT literacy. Students were better able to design, develop, and apply their knowledge in real-world contexts, as well as increase their motivation to learn. This is in line with the objectives of STEM education, which emphasises mastery of concepts, application, and real-world problem-solving (Baran et al., 2021).

In addition to academic aspects, the PjBL-STEM model also improves social skills such as collaboration and communication. Students are trained to work in teams, share ideas, and take responsibility for the results of projects worked on together. These skills are essential in facing the challenges of the 21st century, which demand strong interpersonal skills (Aini & Sari, 2021).

Student responses to the implementation of PjBL-STEM at various educational levels are generally very positive. They feel more challenged, motivated, and actively involved in the learning process. Teachers also report that this model helps them manage more dynamic and participatory classrooms (Risma, 2025).

However, there are several challenges in implementing PjBL-STEM, such as limited facilities and infrastructure, the need for teacher training, and the need to develop objective and comprehensive assessment rubrics. Support from schools and policy makers is essential to optimise the implementation of this model in the field.

Overall, various studies show that the implementation of PjBL-STEM is effective in improving student learning outcomes, science literacy, critical thinking skills, creativity, and collaboration at all levels of education. This model is also relevant in preparing students to face global challenges and the needs of the future world of work.

Thus, the implementation of integrated STEM project-based learning is highly recommended for application at various levels of education. Its consistent effectiveness in improving various aspects of student competencies makes this model one of the relevant and adaptive learning strategies for the demands of 21st-century education. Systemic support, teacher capacity development, and the provision of adequate facilities will further strengthen the success of PjBL-STEM implementation in schools.

Supporting and Hindering Factors for PjBL-STEM Integration

The integration of project-based learning (PjBL) in STEM education has a number of supporting factors that are crucial to its success. One of the main factors is institutional support and school or university management. Commitment from leadership, availability of resources, facilities, and flexible policies provide space for teachers and students to innovate in the implementation of STEM projects. A clean and comfortable school environment, as well as support from the principal and fellow teachers, are also important elements that make students more focused and motivated to learn (Sari & Nita, 2021).

Teacher readiness and competence are the next supporting factors. Teachers who understand the concept of PjBL-STEM and are able to design, manage, and evaluate projects will find it easier to guide students in the learning process. Adequate training and socialisation greatly help teachers in applying this approach effectively in the classroom. In addition, student motivation and readiness to actively participate in projects greatly influence the successful implementation of PjBL-STEM. Students who are enthusiastic and able to work together in groups will find it easier to achieve the expected learning outcomes (Nita & Irwandi, 2021).

Constructive feedback and a comprehensive evaluation system are also important supporting factors. Teachers who provide feedback during the project process can help students correct mistakes and improve the quality of their project outcomes. The use of various assessment techniques such as portfolios, presentations, and peer assessment also enriches the evaluation and learning process (Diana et al., 2021).

However, behind these supporting factors, there are a number of obstacles that are often encountered in the field. One of the main obstacles is the limited facilities and infrastructure to support STEM learning, such as laboratories, experimental equipment, technological devices, and inadequate internet access. These limitations force teachers to innovate using simple materials, even though they still have limitations in explaining abstract concepts optimally (Ma'wa, 2022).

In addition, student readiness and competence also pose their own challenges. Students with low basic skills in reading, arithmetic, or critical thinking often have difficulty following project-based learning that requires high logic and creativity.

Differences in student characteristics, including special needs, also pose challenges in the effective implementation of PjBL-STEM (Anggraini & Wulandari, 2021a). From the teachers' perspective, the lack of further training and socialisation related to the implementation of PjBL-STEM is a significant obstacle.

Teachers often find it difficult to design projects that are relevant and appropriate for students' needs, especially if they are not familiar with the interdisciplinary approach that characterises STEM. Additionally, time management is a constraint because project-based learning requires a longer duration compared to conventional methods, so teachers must be skilled at managing time to ensure all project stages are carried out effectively (Israwaty et al., 2024).

Another challenge arises in the integration of STEM disciplines. Not all teachers possess adequate multidisciplinary knowledge and skills, resulting in suboptimal integration of science, technology, engineering, and mathematics within a single project. The lack of fully integrated teaching materials also poses a challenge in the comprehensive implementation of PjBL-STEM (Anggraini & Wulandari, 2021b).

Thus, the success of PjBL-STEM integration is greatly influenced by institutional support, teacher competence, student motivation, supporting facilities, and a comprehensive evaluation system. On the other hand, limited resources, lack of training, student readiness, time management, and challenges in cross-disciplinary integration are factors that must be addressed systematically. Efforts to enhance teacher capacity, provide facilities, and develop adaptive policies and curricula are essential to optimise the implementation of PjBL-STEM across various levels of education.

Impact on science literacy and 21st century skills

The impact of integrated STEM project-based learning (PjBL-STEM) on science literacy and 21st-century skills has been proven through various studies at the primary and secondary education levels. This model consistently shows significant improvements in students' science literacy, including scientific concept understanding, problem-solving skills, and the application of knowledge in everyday life. One study found that students who participated in PjBL-STEM learning achieved higher science literacy scores compared to those who learned through conventional methods, with the average N-gain of the experimental group reaching 0.76, far above the control group's 0.34 (Cahyono & Aslan, 2025); (Hanif et al., 2021).

In addition to science literacy, PjBL-STEM also has a significant impact on the development of 21st-century skills, known as the 4Cs: Critical Thinking, Communication, Creativity, and Collaboration. Research indicates that this model effectively enhances students' critical thinking skills, creativity, communication abilities, and collaboration.

The average scores for collaboration and communication skills of students who participated in PjBL-STEM learning were in the very good category, with scores of 0.816 and 0.825, respectively (Simamora, 2024). The improvement in science literacy through PjBL-STEM occurred because students were encouraged to actively explore, investigate, and solve real problems relevant to their lives. Project-based learning provides space for students to develop curiosity, conduct experiments, and apply STEM concepts directly. This not only strengthens conceptual understanding but also builds students' confidence and motivation to learn (Simamora, 2022). Critical and creative thinking skills develop because students are faced with challenges that require analysis, synthesis, and innovation in completing projects.

They learn to identify problems, design solutions, and evaluate results independently or in groups. Research indicates that PjBL-STEM contributes 27% to critical thinking skills, 23% to creative thinking, and 20% to creativity, as measured in science education (Auliyani et al., 2025).

Communication and collaboration skills also improve because PjBL-STEM learning requires students to work together, discuss, and present their project results in front of the class. This process trains students to convey ideas effectively, listen to others' opinions, and build solid teamwork.

This collaborative learning environment is crucial in preparing students to face the challenges of the workplace and social life in the future (Hidayati et al., 2023). The effectiveness of PjBL-STEM in improving science literacy and 21st-century skills is also supported by positive responses from students.

Students feel that learning has become more interesting, challenging, and relevant to their needs. Research reports that more than 85% of students gave very positive responses to the implementation of PjBL-STEM, both in terms of improving science literacy, creativity, and group cooperation (Christopoulos et al., 2020).

From the teachers' perspective, this model also encourages increased activity and creativity in designing innovative learning. Teachers act as facilitators guiding students through the exploration and problem-solving process, creating a dynamic and participatory classroom environment. However, to optimise the impact of PjBL-STEM, support in terms of facilities, teacher training, and the development of integrated learning tools is required (Markula & Aksela, 2022).

In conclusion, the implementation of PjBL-STEM has proven effective in improving science literacy and 21st-century skills among students at various educational levels. This model not only strengthens conceptual understanding and learning outcomes but also equips students with critical thinking, creativity, communication, and collaboration skills that are highly sought after in today's globalised and technologically advanced world.

Conclusion

Based on research findings and literature reviews, the implementation of project-based learning with a STEM approach has proven effective in improving various aspects of student competencies. This model is able to significantly encourage creativity, concept mastery, and STEM literacy compared to conventional learning. Students involved in STEM-based projects demonstrate increased creativity in generating innovative solutions to real-world problems, as well as a deeper understanding of concepts and high STEM literacy.

In addition, project-based learning with a STEM approach also contributes to the development of critical thinking, problem solving, collaboration, and communication skills. The active, collaborative, and contextual learning process makes students more motivated, engaged, and able to apply the knowledge they have gained in their daily lives. The implementation of this model has also received positive responses from students, who feel more challenged and ready to face the challenges of the 21st century.

Therefore, it can be concluded that project-based learning with a STEM approach is highly recommended for implementation at various levels of education. Its effectiveness in enhancing creativity, concept mastery, STEM literacy, and 21st-century skills makes this model a relevant and adaptive learning strategy for the educational needs of the present and future.

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