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STEM Project-Based Learning to Enhance Problem-Solving Skills, Collaboration, and Scientific Creativity in Science Education

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ABSTRAK

Penelitian ini bertujuan untuk menganalisis efektivitas STEM Project-Based Learning (STEM-PjBL) dalam meningkatkan keterampilan pemecahan masalah, kolaborasi, dan kreativitas ilmiah siswa dalam pembelajaran IPA. Penelitian ini menggunakan pendekatan kuantitatif dengan desain quasi eksperimen berupa non-equivalent control group. Partisipan penelitian terdiri dari dua kelompok, yaitu kelompok eksperimen yang menerapkan STEM-PjBL dan kelompok kontrol yang menggunakan metode pembelajaran konvensional. Data dikumpulkan melalui tes keterampilan pemecahan masalah, lembar observasi kolaborasi, dan tes kreativitas ilmiah. Hasil penelitian menunjukkan bahwa kelompok eksperimen memperoleh nilai post-test yang lebih tinggi secara signifikan dibandingkan kelompok kontrol pada semua variabel. Analisis normalized gain (N-gain) menunjukkan bahwa peningkatan pada kelompok eksperimen berada pada kategori sedang hingga tinggi, sedangkan kelompok kontrol berada pada kategori rendah hingga sedang. Uji statistik menggunakan independent sample t-test menunjukkan adanya perbedaan yang signifikan antara kedua kelompok ($p < 0,05$). Selain itu, STEM-PjBL terbukti mampu meningkatkan kemampuan siswa dalam menyelesaikan masalah kompleks, bekerja sama dalam tim, serta menghasilkan ide-ide ilmiah yang inovatif. Hasil ini menunjukkan bahwa STEM Project-Based Learning merupakan strategi pembelajaran yang efektif dan inovatif dalam mengembangkan kompetensi penting dalam pendidikan IPA.

Kata Kunci: *STEM project-based learning, keterampilan pemecahan masalah, kolaborasi, kreativitas ilmiah, pendidikan IPA.*

ABSTRACT

This study aims to investigate the effectiveness of STEM Project-Based Learning (STEM-PjBL) in enhancing students' problem-solving skills, collaboration, and scientific creativity in science education. The research employed a quantitative approach using a quasi-experimental design with a non-equivalent control group. The participants consisted of two groups: an experimental group that engaged in STEM-PjBL and a control group that received conventional instruction. Data were collected using a problem-solving skills test, a collaboration observation sheet, and a scientific creativity test. The results showed that the experimental group achieved significantly higher post-test scores compared to the control group across all variables. The normalized gain (N-gain) analysis indicated that the experimental group reached a medium to high level of improvement, while the control group remained in the low to medium category. Statistical analysis using an independent sample t-test revealed a significant difference between the two groups ($p < 0.05$). Furthermore, STEM-PjBL effectively improved students' ability to solve complex problems, collaborate in teams, and generate innovative scientific ideas. These findings suggest that STEM Project-Based Learning is an effective and innovative instructional strategy for developing essential competencies in science education.

Keywords: *STEM project-based learning, problem-solving skills, collaboration, scientific creativity, science education.*

INTRODUCTION

The integration of STEM (Science, Technology, Engineering, and Mathematics) education with Project-Based Learning (PjBL) has gained significant attention as an

innovative approach to improve the quality of science education in the 21st century (Maspul, 2024). STEM-PjBL emphasizes active learning through real-world problem-solving, interdisciplinary integration, and collaborative engagement, enabling students to develop essential competencies beyond content knowledge (Pramasdyahsari et al., 2026). Recent studies highlight that STEM-based project learning environments significantly enhance students' engagement, creativity, and problem-solving skills by situating learning within authentic and meaningful contexts (Thibaut et al., 2020; Kang, 2021; Anwar et al., 2022).

One of the key challenges in science education is the limited development of students' problem-solving skills, particularly in complex and ill-structured situations (Geirsdotter Bækkelund et al., 2025). Traditional instructional approaches often focus on procedural knowledge and factual recall, which may not adequately prepare students for real-world challenges. STEM-PjBL addresses this issue by engaging students in inquiry-driven projects that require them to identify problems, design solutions, test hypotheses, and evaluate outcomes (Doyan et al., 2026). Empirical evidence suggests that students who participate in STEM project-based learning demonstrate significantly higher levels of problem-solving ability and critical thinking compared to those in conventional classrooms (Kang, 2021; Anwar et al., 2022; Han et al., 2021).

In addition to problem-solving, collaboration is another essential competency emphasized in STEM education (Lin et al., 2023). STEM-PjBL encourages students to work in teams, share ideas, and collaboratively develop solutions, thereby fostering communication and teamwork skills (Nurfazlina et al., 2025). Research indicates that collaborative learning environments enhance students' social interaction, knowledge construction, and overall learning performance (Han et al., 2021; Margot & Kettler, 2020; Anwar et al., 2022). Through collaborative projects, students are exposed to diverse perspectives, which contribute to deeper understanding and more innovative problem-solving approaches.

Furthermore, STEM-PjBL has been shown to significantly enhance students' scientific creativity, which involves the ability to generate novel ideas, design innovative solutions, and apply scientific concepts in creative ways (Prajoko et al., 2023). Scientific creativity is increasingly recognized as a critical component of science education, particularly in preparing students for future careers in STEM fields. Studies demonstrate that project-based learning environments stimulate creativity by encouraging exploration, experimentation, and iterative design processes (Thibaut et al., 2020; Kang, 2021; Han et al., 2021).

Despite its potential, the implementation of STEM-PjBL faces several challenges, including limited teacher experience, insufficient resources, and difficulties in integrating interdisciplinary content. Additionally, variations in instructional design and project implementation may lead to inconsistent learning outcomes. Previous research emphasizes the importance of structured guidance, clear learning objectives, and effective facilitation in ensuring the success of STEM-PjBL (Margot & Kettler, 2020; Anwar et al., 2022; Kang, 2021).

Moreover, while existing studies have explored the impact of STEM-PjBL on individual variables such as problem-solving or collaboration, there is still limited research examining its integrated effect on multiple competencies simultaneously, particularly problem-solving skills, collaboration, and scientific creativity. Addressing this gap is essential for developing a more comprehensive understanding of the effectiveness of STEM-PjBL in science education.

Therefore, this study aims to investigate the effectiveness of STEM project-based learning in enhancing students' problem-solving skills, collaboration, and scientific

creativity in science education. The findings of this study are expected to contribute to the development of innovative instructional strategies that support holistic competency development and prepare students for the demands of the 21st century.

METHOD

This study employed a quantitative research approach using a quasi-experimental design with a non-equivalent control group to investigate the effectiveness of STEM Project-Based Learning (STEM-PjBL) in enhancing students' problem-solving skills, collaboration, and scientific creativity in science education. This design was selected due to its suitability for educational settings where random assignment is not feasible, while still allowing for systematic comparison between experimental and control groups (Creswell & Creswell, 2021).

The research was conducted in a secondary school involving two groups of students (Widyorini & Rahayu, 2023). The experimental group was taught using STEM-PjBL, which integrated science, technology, engineering, and mathematics through project-based activities, while the control group received conventional teacher-centered instruction (Diani et al., 2025). The STEM-PjBL approach engaged students in solving real-world problems through collaborative projects that required planning, designing, testing, and evaluating solutions. Participants were selected using purposive sampling to ensure that both groups had comparable academic backgrounds and learning characteristics.

Data were collected using three main instruments: a problem-solving skills test, a collaboration skills observation sheet, and a scientific creativity test. The problem-solving test measured students' ability to identify problems, generate solutions, and evaluate outcomes. The collaboration instrument assessed students' participation, communication, teamwork, and responsibility during group activities. Meanwhile, the scientific creativity test evaluated students' ability to generate original ideas, propose innovative solutions, and apply scientific concepts creatively. All instruments were validated through expert judgment and pilot testing to ensure validity and reliability.

The intervention was conducted over several instructional sessions, during which students in the experimental group worked collaboratively on STEM-based projects. These projects involved identifying real-world problems, designing solutions, building prototypes, and presenting their findings. Previous research indicates that STEM-PjBL enhances students' problem-solving and collaboration skills by engaging them in authentic and interdisciplinary learning experiences (Anwar et al., 2022; Han et al., 2021; Thibaut et al., 2020).

Prior to the main study, a pilot test was conducted to evaluate the reliability of the instruments using Cronbach's alpha coefficient. Data analysis included descriptive statistics to summarize students' performance and inferential statistics, such as independent sample t-tests and normalized gain (N-gain), to determine the effectiveness of the intervention. Statistical analysis was conducted using SPSS software with a significance level set at 0.05. This methodological approach is consistent with recent studies emphasizing the effectiveness of STEM-PjBL in improving multiple competencies, including problem-solving, collaboration, and creativity, through student-centered and inquiry-based learning environments (Anwar et al., 2022; Kang, 2021; Margot & Kettler, 2020).

RESULTS AND DISCUSSION

Descriptive Statistics of Learning Outcomes

The descriptive statistical analysis revealed that both the experimental and control groups experienced improvements in their post-test scores across all measured variables, including problem-solving skills, collaboration, and scientific creativity. However, the experimental group, which participated in STEM Project-Based Learning (STEM-PjBL), demonstrated a significantly greater improvement compared to the control group. The similarity in pre-test scores between the two groups indicates that students had relatively equal initial competencies, thereby strengthening the validity of the findings.

A more detailed analysis of the post-test scores shows that students in the experimental group achieved higher mean scores in all three variables. This suggests that STEM-PjBL provides a more effective learning environment compared to traditional instructional methods. The integration of interdisciplinary content and real-world problem-solving tasks allows students to engage in meaningful learning experiences, which enhances their understanding and performance.

Furthermore, the active and collaborative nature of STEM-PjBL encourages students to take ownership of their learning. By engaging in hands-on projects, students are able to apply theoretical knowledge in practical contexts, leading to deeper understanding and improved learning outcomes. In contrast, the control group, which relied on conventional instruction, showed limited improvement due to the passive nature of the learning process.

Normalized Gain (N-gain) Analysis

The normalized gain (N-gain) analysis indicated that the experimental group achieved a medium to high level of improvement across all variables, whereas the control group remained within the low to medium category. Among the three variables, the highest gain was observed in collaboration skills, followed by problem-solving skills and scientific creativity.

This finding highlights the effectiveness of STEM-PjBL in promoting collaborative learning. The project-based approach requires students to work in teams, share ideas, and collectively solve problems, which enhances their collaboration skills. The structured nature of the projects ensures that all students actively participate, thereby improving their communication and teamwork abilities.

Additionally, the improvement in problem-solving skills reflects the impact of STEM-PjBL in fostering higher-order thinking. Students are required to identify problems, develop solutions, and evaluate outcomes, which promotes critical and analytical thinking. The iterative nature of project-based learning allows students to refine their solutions and learn from their mistakes, leading to improved problem-solving abilities.

Moreover, the moderate improvement in scientific creativity suggests that STEM-PjBL provides opportunities for creative expression and innovation. However, creativity development may require longer exposure and more open-ended tasks to reach higher levels of improvement.

Problem-Solving Skills Analysis

The results showed that students in the experimental group demonstrated a significant improvement in their problem-solving skills compared to those in the control group. Students were able to identify problems more effectively, generate multiple solutions, and evaluate the feasibility of their approaches.

This improvement can be attributed to the authentic and contextual nature of STEM-PjBL tasks. By engaging in real-world problems, students are encouraged to apply

their knowledge in meaningful ways. The interdisciplinary nature of STEM learning also allows students to integrate concepts from different domains, leading to more comprehensive and effective problem-solving strategies.

Furthermore, the iterative design process inherent in project-based learning enables students to refine their solutions through trial and error. This process not only enhances problem-solving skills but also fosters resilience and persistence. Students learn to view challenges as opportunities for learning, which contributes to their overall development.

Collaboration Skills Analysis

The analysis of collaboration skills revealed that students in the experimental group showed significant improvement in their ability to work effectively in teams. Students demonstrated better communication, coordination, and mutual support during group activities.

This improvement is largely due to the collaborative nature of STEM-PjBL, which requires students to work together to achieve common goals. Through group discussions and shared responsibilities, students develop interpersonal skills and learn to appreciate diverse perspectives.

In addition, the structured nature of the projects ensures that each student has a specific role, which promotes accountability and active participation. This structure helps to minimize issues such as social loafing and ensures that all group members contribute to the project.

Moreover, collaboration in STEM-PjBL fosters a sense of community and belonging among students. This positive social environment enhances motivation and engagement, leading to improved learning outcomes.

Scientific Creativity Analysis

The results also indicated a significant improvement in scientific creativity among students in the experimental group. Students demonstrated an increased ability to generate original ideas, propose innovative solutions, and apply scientific concepts creatively.

This improvement can be linked to the open-ended nature of STEM-PjBL tasks, which encourage exploration and experimentation. Students are given the freedom to design their own solutions, which promotes creative thinking and innovation.

Furthermore, the integration of multiple disciplines in STEM learning provides students with diverse perspectives and tools, which enhances their ability to think creatively. By combining knowledge from science, technology, engineering, and mathematics, students are able to develop more innovative and effective solutions.

However, the level of improvement in creativity was slightly lower compared to collaboration and problem-solving. This suggests that creativity development may require more time and exposure to open-ended and exploratory learning environments.

Discussion

1. Effectiveness of STEM-PjBL

The findings of this study confirm that STEM Project-Based Learning significantly improves students' problem-solving skills, collaboration, and scientific creativity. This result is consistent with Anwar et al. (2022), who found that STEM-PjBL enhances students' engagement and learning outcomes through authentic and interdisciplinary learning experiences. Similarly, Han et al. (2021) emphasized that project-based learning fosters critical thinking and collaboration by engaging students in real-world problem-solving.

Furthermore, Thibaut et al. (2020) highlighted that integrated STEM education promotes deeper understanding and skill development by combining multiple

disciplines. The findings of this study support these conclusions, demonstrating that STEM-PjBL provides an effective framework for developing essential competencies in science education.

2. Development of Problem-Solving Skills

The significant improvement in problem-solving skills observed in this study can be explained by the emphasis on inquiry and real-world application in STEM-PjBL. Students are required to actively engage in problem identification, solution design, and evaluation, which promotes higher-order thinking.

This finding aligns with Kang (2021), who noted that STEM education enhances problem-solving skills by encouraging interdisciplinary thinking and practical application. Additionally, Anwar et al. (2022) emphasized that project-based learning provides opportunities for students to develop and refine their problem-solving strategies.

3. Enhancement of Collaboration Skills

The improvement in collaboration skills highlights the importance of teamwork in STEM education. The project-based approach requires students to work together, share ideas, and support each other, which enhances their communication and interpersonal skills.

This finding is supported by Margot and Kettler (2020), who reported that STEM integration promotes collaborative learning and improves student interaction. Furthermore, Han et al. (2021) emphasized that collaborative learning environments enhance student engagement and performance.

4. Development of Scientific Creativity

The improvement in scientific creativity indicates that STEM-PjBL provides an effective environment for fostering innovation. Students are encouraged to explore new ideas and develop creative solutions, which enhances their creative thinking skills.

This finding is consistent with Thibaut et al. (2020), who highlighted that project-based learning stimulates creativity by encouraging exploration and experimentation. Additionally, Kang (2021) emphasized that STEM education promotes creativity through interdisciplinary integration.

CONCLUSION

This study concludes that the implementation of STEM Project-Based Learning (STEM-PjBL) has a significant and multidimensional impact on improving students' problem-solving skills, collaboration, and scientific creativity in science education. The findings demonstrate that students who participated in STEM-PjBL outperformed those in conventional learning environments across all measured variables. The integration of interdisciplinary content with real-world problem-solving activities enables students to develop a deeper understanding of scientific concepts while simultaneously enhancing essential 21st-century competencies.

Furthermore, STEM-PjBL proves to be particularly effective in fostering problem-solving skills by engaging students in authentic tasks that require critical analysis, solution design, and iterative evaluation. The structured yet flexible nature of project-based learning encourages students to explore multiple approaches, refine their ideas, and develop resilience in facing complex challenges. In addition, the collaborative aspect of STEM-PjBL significantly enhances students' ability to work in teams, communicate effectively, and share responsibility in achieving common goals.

The study also highlights the important role of STEM-PjBL in developing scientific creativity. Through open-ended and inquiry-driven projects, students are encouraged to generate innovative ideas, design creative solutions, and apply scientific knowledge in

novel ways. Although the improvement in creativity is evident, it suggests that sustained and continuous implementation of STEM-PjBL is necessary to maximize its impact on creative development. The novelty of this study lies in its integrated analysis of three key competencies problem-solving skills, collaboration, and scientific creativity within a single STEM-PjBL framework. This comprehensive approach provides a more holistic understanding of how project-based and interdisciplinary learning environments contribute to student development. It also reinforces the importance of combining cognitive, social, and creative dimensions in science education.

However, the successful implementation of STEM-PjBL requires careful instructional planning, adequate resources, and teacher readiness. Educators must be equipped with the necessary skills to design meaningful projects, facilitate collaboration, and guide students through inquiry processes. Additionally, institutional support is essential to provide the infrastructure and learning environment needed for effective STEM implementation. In conclusion, STEM Project-Based Learning represents an innovative and effective instructional approach for enhancing key competencies in science education. By promoting active learning, collaboration, and creativity, STEM-PjBL prepares students to complex real-world challenges and equips them with the skills necessary for success in the 21st century.

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