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The Effectiveness of STEM-Based Project-Based Learning (PjBL) Model in Improving Elementary School Students' Science Learning Outcomes

Rahma Diani[1*], Yuberti[2], Ida Fiteriani[3], Renita Lestari[4], Mega Aria Monica[5]

[1,2,3,4,5]Universitas Islam Negeri Raden Intan Lampung, Lampung, Indonesia

*Correspondence adress: rahmadiani@radenintan.ac.id

Abstract

This study aims to determine the effectiveness of the STEM-based project-based learning (PjBL) model in improving students' basic science learning outcomes. The study was conducted at MIS Darul Huda Campang Jaya, Bandar Lampung. This study employed a quantitative method with a quasi-experimental design, specifically the pretest and posttest control group design. The sample consisted of 78 students, divided equally into an experimental class (39 students) and a control class (39 students), selected via simple random sampling. The research instrument was a 20-item multiple-choice science achievement test, which was validated by two science education experts and one science teacher. The validity of each test item was analyzed using Pearson Product-Moment Correlation, while reliability testing using Cronbach's Alpha obtained a coefficient of 0.86, indicating high reliability. Data analysis techniques included normality testing with the Kolmogorov–Smirnov test, homogeneity testing with Levene's Test, and hypothesis testing with the independent-samples t-test. The results showed that the significance value of 0.000 < 0.05 indicated a significant difference in students' science learning outcomes between the experimental and control classes. The findings confirmed that implementing the STEM-based PjBL model effectively improved conceptual understanding, critical thinking, and collaboration skills through contextual, hands-on learning experiences. Therefore, this model can be recommended as an innovative approach to enhancing 21st-century competencies in elementary school science learning.

Keywords: Elementary School, Learning Outcomes, Project-Based Learning (PjBL), Science Education, STEM.

Abstrak

Penelitian ini bertujuan untuk mengetahui efektivitas model pembelajaran berbasis proyek (PjBL) berbasis STEM dalam meningkatkan hasil belajar Ilmu Pengetahuan Alam siswa. Penelitian ini dilakukan di MIS Darul Huda Campang Jaya, Bandar Lampung. Penelitian ini menggunakan metode kuantitatif dengan desain kuasi-eksperimental, khususnya desain kelompok kontrol pretest dan posttest. Sampel terdiri dari 78 siswa, dibagi rata menjadi kelas eksperimen (39 siswa) dan kelas kontrol (39 siswa), dipilih melalui teknik random sampling. Instrumen penelitian berupa tes prestasi sains pilihan ganda 20 butir soal, yang telah divalidasi oleh dua ahli pendidikan sains dan satu guru sains. Validitas setiap butir soal dianalisis menggunakan Korelasi Momen Produk Pearson, sedangkan pengujian reliabilitas menggunakan Alpha Cronbach memperoleh koefisien 0,86, menunjukkan reliabilitas yang tinggi. Teknik analisis data meliputi pengujian normalitas dengan uji Kolmogorov–Smirnov, pengujian homogenitas dengan Uji Levene, dan pengujian hipotesis dengan uji t sampel independen. Hasil penelitian menunjukkan bahwa nilai signifikansi 0,000 < 0,05 mengindikasikan perbedaan yang signifikan dalam hasil belajar sains siswa antara kelas eksperimen dan kelas kontrol. Temuan ini menegaskan bahwa penerapan model PjBL berbasis STEM secara

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efektif meningkatkan pemahaman konseptual, berpikir kritis, dan keterampilan kolaborasi melalui pengalaman belajar kontekstual dan praktik langsung. Oleh karena itu, model ini dapat direkomendasikan sebagai pendekatan inovatif untuk meningkatkan kompetensi abad ke-21 dalam pembelajaran sains di sekolah dasar.

Kata kunci: *Sekolah Dasar, Hasil Belajar, Pembelajaran Berbasis Proyek (PjBL), Pembeljaran Sains, STEM.*

INTRODUCTION

Advances in science and technology have brought about profound changes (Wahid, 2018; Wolff, 2021). Therefore, one of the demands for a developing country like Indonesia to compete with developed nations is to prepare highly competitive human resources (Isadaud et al., 2022; Pratiwi, 2017). Fostering creative thinking in students, starting at the school level, should be a priority for all educators (Harris & De Bruin, 2018; Noviyana, 2017). Teachers can make these efforts, including the implementation of innovative learning models (Nurhadiyati et al., 2020). These fun activities encourage children to develop their own creativity (Surya et al., 2018).

The choice of learning model also influences success in achieving learning objectives (Aini et al., 2022; Al-Adwan et al., 2021; Eom & Ashill, 2018). Learning models are generally designed based on guidelines or foundations (Collins et al., 2016; Khoerunnisa & Aqwal, 2020). To achieve learning objectives, teachers need to choose appropriate and effective learning objectives (Mirdad, 2020; Mitchell & Manzo, 2018). PjBL utilizes projects as a learning method that encourages students to achieve affective, cognitive, and psychomotor competencies (Octavia, 2020; Wulandari et al., 2024). Teachers assign tasks to students to achieve various learning outcomes through exploration, assessment, interpretation, synthesis, and information gathering (Hidayat, 2021; Thurlings & den Brok, 2017; Zeng et al., 2018).

STEM (Science, Technology, Engineering, and Mathematics) learning involves developing students' critical thinking, collaboration, and analytical skills in combining concepts and processes from science, technology, engineering, and mathematics into situations relevant to students' lives, to improve applicable competencies and skills (Diani et al., 2024; Zuryanty et al., 2020). The goal of STEM is to produce students who are ready to enter society, able to develop their competencies so they can be applied in various situations and problems encountered in everyday life. (Hilton & Pellegrino, 2012; Utami et al., 2018; Yunita et al., 2024)

STEM-based PjBL has the following steps: 1. Reflection (guiding students to understand the context of the problem and encouraging them to conduct investigations) 2. Research (in science concepts, students gather information from relevant sources) 3. Discovery (the discovery stage generally bridges the study and information already familiar to the project steps) 4. Application (the stage where students solve problems and test the models they have designed based on the results of their tests) 5. Communication (presenting the results of a product or solution) (Agung et al., 2022; Lestari & Diana, 2018; Wardani et al., 2021).

Implementing a project-based learning model based on STEM principles can contribute to increasing student motivation, providing meaningful learning experiences, and encouraging students to develop problem-solving skills (Afifah et al., 2019; Maspul, 2024). The PjBL and STEM models have complementary strengths and weaknesses. In PjBL, students understand concepts by creating products, whereas in STEM learning, the process of designing and redesigning (engineering design processes) enables students to produce their best products (Erlinawati et al., 2017; Fita et al., 2021; Rudianto et al., 2022).

The STEM-based PjBL model is relevant to science learning because it aligns with the nature of science as a process of inquiry, concept discovery, and problem-solving. STEM learning integrates science, technology, engineering, and mathematics in authentic contexts, enabling students to build conceptual understanding through investigative and exploratory activities that are close to everyday life (Retno et al., 2025). When combined with PjBL, students not only understand the concepts theoretically but also apply them through the product design process and problem-solving using an engineering design process approach, which is proven to strengthen conceptual mastery and high-level thinking skills (Lin et al., 2021).

Learning outcomes refer to the changes achieved after undergoing a learning process (Afriyansya, 2025). These changes refer to the taxonomy of instructional objectives developed by Bloom, Simpson, and Harrow, which covers cognitive, affective, and psychomotor aspects (Hernawati, 2018). High student learning outcomes are necessary in every subject during the learning process (Juniati & Widiana, 2017). High student learning achievement is essential in every subject during the learning process. However, the results of science learning on Theme 1, "The Beauty of Togetherness," Subtheme 1, "Cultural Diversity of My Nation," in class IV at MIS Darul Huda Campang Jaya still show low achievement. Based on the results of observations (Observasi, 2025), the field of students' mastery of concepts related to the theme has not yet reached the set standards. This is reinforced by the formative assessment results, which show an average value of 40% for class IV A and 50% for class IV B, where more than half of the students have not met the Minimum Completion Criteria (KKM), which is 70%. Furthermore, interviews with science teachers (interview, 2025) revealed that low learning outcomes are influenced by several factors, including teacher-centered learning, minimal use of contextual media relevant to students' daily lives, and limited opportunities for students to engage in inquiry-based activities and hands-on practice. This situation indicates the need for more active, context-based learning models that encourage direct student involvement in the learning process.

Based on problems identified at MIS Darul Huda Campang Jaya and supported by previous research, this study aims to determine the effect of the STEM-based PjBL model on the science learning outcomes of fourth-grade students. The application of this learning model is expected to improve students' understanding of science concepts, develop their critical and creative thinking, and apply their knowledge in real-life contexts. The results of this study are also expected to contribute to the development of innovative learning strategies that support the improvement of science learning quality at the elementary education level.

METHOD

This study used a quantitative research method with a quasi-experimental design. The design employed was a pretest-posttest control group design, comprising two groups that received different treatments: the experimental group and the control group (Chang et al., 2022; Siedlecki, 2020). The experimental group was taught using a STEM-based PjBL model, while the control group was taught using a teacher-centred learning model. This design was chosen because the research subjects could not be selected entirely at random, yet still allowed valid comparisons between the two groups.

The subjects of this study were all fourth-grade students of MIS Darul Huda Campang Jaya, Sukabumi Regency, Bandar Lampung City. The study population consisted of 78 students, divided into two classes: IV A and IV B. Using a simple random sampling technique, class IV A was selected as the experimental class (39 students). In comparison, class IV B was designated as the control class (39 students). The object of this study was students' science learning outcomes on the theme "The Beauty of Togetherness" and the subtheme "Cultural Diversity of My Nation".

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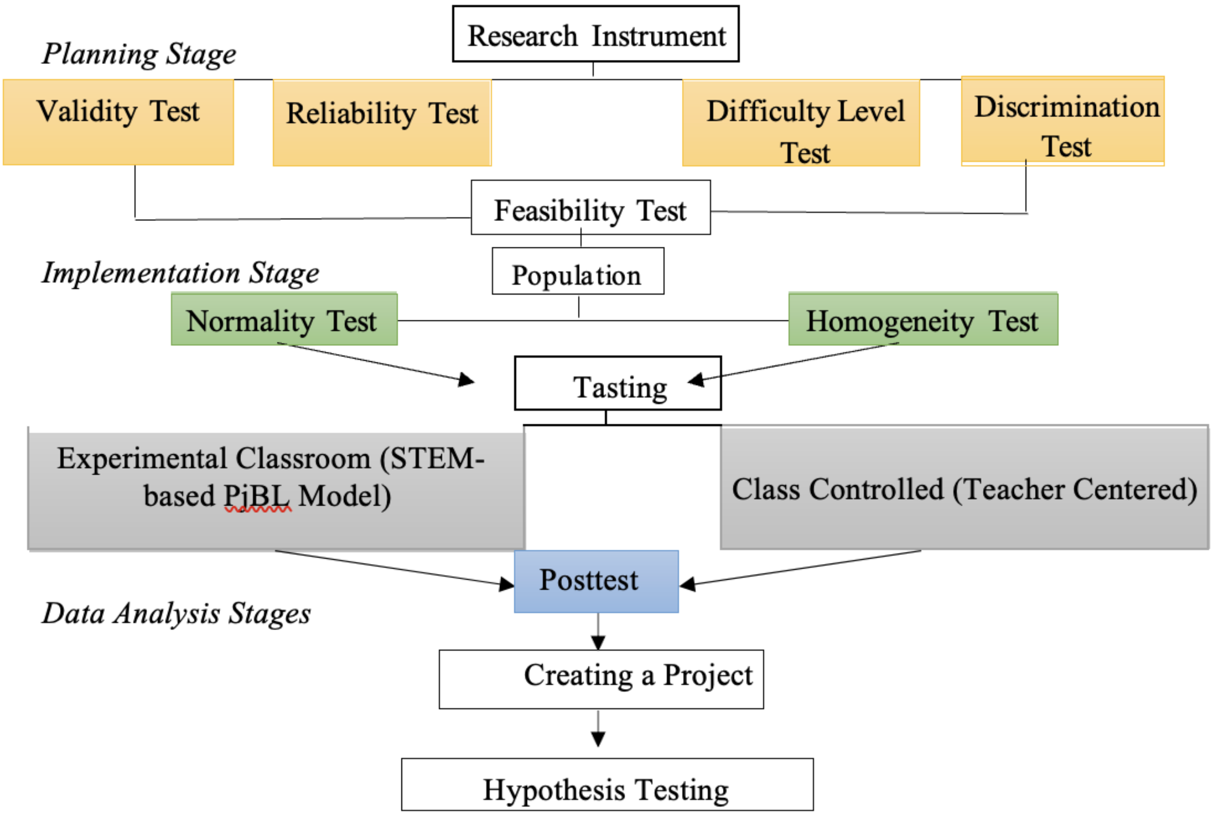

Figure 1. Research Procedure

Data were collected through a science achievement test administered twice: once before the treatment (pretest) and again after the treatment (posttest). The test consisted of 20 multiple-choice questions designed to measure various cognitive levels based on the Revised Bloom's Taxonomy (C1–C6). The test items were developed in accordance with the fourth-grade science curriculum. They included indicators such as: (1) understanding the concept of energy and its transformation, (2) identifying energy sources in everyday life, (3) analyzing the relationship between energy and environmental aspects, and (4) applying energy concepts in solving simple problems. Both the pretest and posttest used the same set of items but were administered at different times to evaluate the improvements in student learning after the treatment. The instrument was validated by two science education experts and one practicing science teacher. Reliability testing using SPSS v.25 produced a Cronbach's Alpha coefficient of 0.83, indicating that the test is reliable. Classroom observations were also conducted to ensure that the implementation of the STEM-based PjBL model followed five key stages: reflection, research, discovery, application, and communication (Baharin et al., 2018; Khoiriyah, 2020).

The research procedure consists of three stages: (1) Planning, preparing the learning plan, instruments, and validation process, (2) Implementation, providing a pretest, conducting learning interventions in the experimental class using the STEM-PjBL model, and implementing conventional learning in the control class for four meetings, and (3) Evaluation, providing a posttest and conducting data analysis (Hidayati et al., 2024; Rahmawati et al., 2021; Rudianto et al., 2022). Pretest and posttest data were analyzed using SPSS version 25. Statistical analysis included a normality test (Kolmogorov–Smirnov), a homogeneity-of-variance test (Levene test), and an independent-samples t-test to determine whether there were significant differences between the experimental and control groups. The results were considered statistically significant if the Sig. (2-tailed) value was less than 0.05.

RESULTS AND DISCUSSION

The data in this study were obtained from a 20-question multiple-choice science test given as a pretest and a posttest. The experimental class consisted of 39 students, and the control class consisted of an equal number of 39 students. The instrument has been validated and shows a reliability coefficient of α = 0.86, indicating high reliability. The results were then analyzed using normality, homogeneity, and t-test tests to determine the effect of the STEM-based PjBL model on students' science learning outcomes. The STEM-based PjBL model is combined with the STEM approach, in which students use relevant knowledge sources to address challenges they face in everyday life, thereby producing products as solutions. The learning steps used in This study includes:

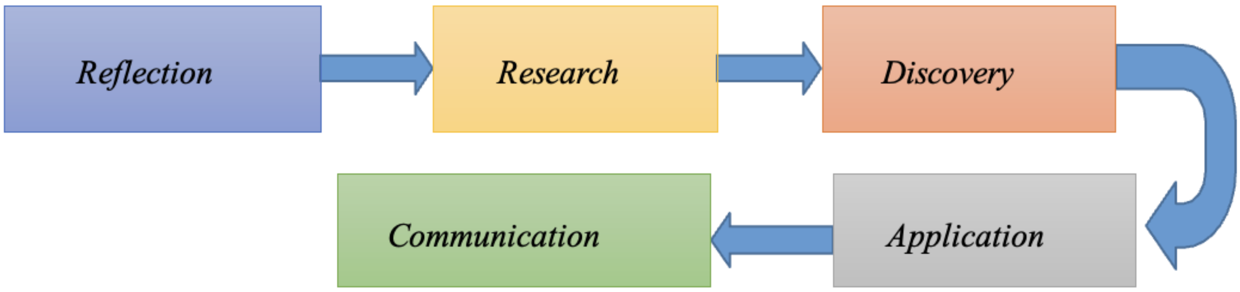

Figure 2. The Pre-learning Steps of STEM-based PjBL

In the reflection phase, students were introduced to real-life problems related to energy sources and their applications in everyday life. Observations showed that most students (85%) were able to express their initial experiences and identify basic problems related to energy issues. This indicates that the reflection phase successfully built students' initial connection to the learning context. In the research phase, students sought information from textbooks, simple learning videos, and digital resources. Eighty percent of students were able to collect appropriate data and identify types of renewable energy and their benefits. This activity demonstrated improved scientific literacy skills and increased student engagement.

Furthermore, in the discovery phase, students began to develop project ideas based on the information they had collected. Students worked in small groups to design initial models. Observations revealed that students were able to connect scientific concepts with design steps, as demonstrated by their ability to design a simple water filter prototype. This demonstrates students' ability to analyze and synthesize information. In the application phase, student groups created and tested prototypes based on their designs. Observational data showed that most students were able to apply science concepts directly to solve real-world problems. Project results demonstrated the application of physics concepts, including pressure, filterability, and material efficiency. This demonstrated improved problem-solving and practical skills. In the communication phase, students presented their products and findings to the class. Approximately 90% of students were able to confidently explain the product design, its functionality, and the underlying science concepts. Group presentations demonstrated improved scientific communication, argumentation, and collaboration skills among group members.

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Table 1. STEM-based PjBL Model

No	Steps for STEM-Based PjBL Model	Implementation of STEM-Based PjBL Model
1.	***Reflection:*** students are presented with problems that train their memory skills (C1).	
2.	***Research:*** Students explore information from relevant sources (understand C2).	
3.	***Discovery:*** Students work in groups to develop project steps (applying C3, analyzing C4).	
4.	***Application:*** students solve problems (evaluate C5)	

5. ***Communication:*** Students create a product and then present the results of their problem-solving (solution/product) (creating C6).	

After obtaining qualitative results from STEM-PjBL implementation through classroom observations, a quantitative analysis was conducted to assess the model's impact on students' science achievement. The following presents the statistical analysis of the findings.

Table 2. Normality Test of Science Learning Outcomes

	Class	***Signature (Kolmogorov-Smirnov ᵃ)***	***Signature value α = 0.05***	**Conclusion**
Science is learning Results	Experimental Pretest	0.107	0.05	Normal Distribution
	Experimental Posttest	0.157		
	Pretest Control	0.200		
	Control Posts	0.200		

The results of the normality test using the Kolmogorov–Smirnov method showed a significance value above 0.05, indicating that the data were normally distributed. Levene's test for homogeneity of variances yielded a p-value of 0.063 (>0.05), indicating that the variances are equal across groups. The independent-samples t-test showed a p-value of 0.000 (<0.05), indicating a significant difference between the experimental and control groups. The experimental group's average posttest score was higher, confirming that the STEM-based PjBL model significantly improved students' science learning outcomes.

Table 3. Homogeneity Test of Science Learning Outcomes

		Levene Statistics	DF1	DF2	Signature.
Science Learning Outcomes	Based on Average	1,530	3	76	.063
	Based on Median	1,262	3	76	.103
	Based on Median and df adjusted for i	1,262	3	71,036	.105
	Based on the trimmed mean	1,430	3	76	.076

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The homogeneity test was conducted using Levene's test statistic. The decision criterion was established: if the mean exceeds 0.05, the data are declared homogeneous. Analysis of the results showed that the pretest and posttest data yielded a sig value of 0.63, indicating that the data are homogeneous. After ensuring that the dataset met the assumptions of normality and homogeneity, an independent-samples t-test was conducted in SPSS (version 25).

Table 4. Independent Samples t-test Results for Science Learning

Independent Samples Test										
	Lavena's Test for Equality of Variances		t-Test for Equality of Means						**95% Confidence Interval is the Difference**	
Science learning Results		F	Signature	T	Df	Sig. (2-tail)	Meaning Difference	Etd . Difference Error	Lower	On
	Equivalent variance assumed	.393	.535	3,945	38	0.000	8,300	2.104	4,041	12,559
	Equal variance is not assumed			3,945	37.60	0.000	8,300	2.104	4,039	12,561

An independent-samples t-test was employed to examine differences in posttest scores between the experimental and control groups in SPSS version 25. The decision criterion was set such that if the mean value obtained is less than 0.05, the alternative hypothesis (H_1) will be accepted. Based on the analysis of the results listed in Table 4.7, a significance value of 0.000 (2-tailed, equal variance not assumed) was obtained. This value indicates that 0.000 < 0.05; hence, H_1 is accepted, indicating that the STEM-Based PjBL model has a significant influence on students' science learning outcomes.

Findings from the posttest analysis suggest that adopting a STEM-based PjBL framework improves students' learning outcomes. The evidence from the hypothesis indicates a relationship between the application of a STEM-based PjBL model and improved science learning outcomes, particularly in materials, the environment, and energy sources in everyday life. If learning remains teacher-centered and does not utilize the potential of the environment, students merely play the role of recipients of information, without the opportunity to develop themselves or utilize the environment as a resource. Therefore, a learning model and media are needed to foster active participation, effectiveness, and the skills needed in design projects as solutions to problems. Through this type of learning, students gain hands-on experience and a contextual understanding that can be applied in real-life situations.

The project-based learning model (PjBL) Integrated with STEM is a learning approach that enables students to combine various aspects of STEM within the learning process (AlAli, 2024). This approach has a positive impact on science learning outcomes by providing valid and meaningful learning experiences. Through projects, students are trained to think analytically and creatively, and to develop the ability to solve problems encountered in everyday life (Amri et al., 2020; Chen et al., 2022).

The adoption of STEM-Based PjBL provides students with the opportunity to practice solving real-world problems in everyday life. Students actively answer teacher questions, either individually or in groups, as the learning process is designed around direct experience and contextual problems close to their environment. In this learning process, students seek solutions based on reliable sources, such as in a project to make a water filter from used bottles. The project results are presented to the class as a form of accountability and reflection on the learning process. Thus, STEM-based PjBL is a learning approach that begins with a problem and culminates in the creation of a product, thereby developing critical thinking skills, creativity, and meaningful learning activities to improve student learning outcomes.

The findings of this study indicate that the implementation of the STEM-based PjBL model has been effective in the field through five main stages, namely reflection, research, discovery, application, and communication, where students are actively involved in identifying problems, conducting simple investigations, designing projects, making prototypes, and presenting the results. This structured process enables students to connect scientific concepts to real-life contexts, leading to a better understanding and higher posttest scores in the experimental class compared to the control class. The effectiveness of this model lies in its ability to encourage active, collaborative, and contextual learning, allowing students to construct knowledge through authentic experiences, as supported by (Baharin et al., 2018; Fauzi et al., 2024; Retno et al., 2025), who emphasize that integrating STEM in project-based learning improves conceptual mastery and higher-order thinking. Furthermore, this model enhances creativity, teamwork, and communication skills (Erlinawati et al., 2017; Zuryanty et al., 2020), which align with the core values of 21st-century education. However, several limitations were identified, including longer implementation time, the need for adequate materials, and the requirement for well-prepared classroom management (Diani & Hartati, 2018; Rahmawati et al., 2021; Yuberti et al., 2024). Overall, this study confirms that the STEM-based PjBL model can significantly enhance students' science learning outcomes and provide meaningful learning experiences that align with the objectives of the Independent Curriculum. Future research is recommended to expand this study by examining the model's impact on students' scientific attitudes, creativity, and problem-solving abilities across various grade levels and science topics, thereby strengthening its empirical validity and classroom applicability. Therefore, the STEM-PjBL model not only improves cognitive achievement but also fosters scientific thinking and positive attitudes toward learning science. In conclusion, the STEM-based PjBL model is a practical approach for elementary science instruction. It aligns with 21st-century learning goals by promoting higher-order thinking skills, creativity, and collaboration through real-world problem-solving.

CONCLUSION

Based on the findings and discussion, this study concludes that implementing the STEM-based PjBL model significantly improves elementary school students' science learning outcomes compared to conventional instruction. Key findings highlight that students' active engagement in the five learning stages of reflection, research, discovery, application, and communication contributes to deeper conceptual understanding, critical thinking, and collaboration skills. This study also contributes to theory by demonstrating that integrating STEM principles in project-based learning enhances meaningful learning and bridges the gap between theory and practice, particularly in elementary school science education. In practice, it provides teachers with an alternative pedagogical approach to developing students' 21st-century competencies through context-based inquiry. However, this study has several limitations, including a relatively small sample size, limited implementation duration, and reliance on the quality of teacher facilitation, which may affect the generalizability of the results. Future research is recommended to explore the long-term effects of the

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STEM-based PjBL model on students' creativity, scientific attitudes, and problem-solving abilities across different grade levels and science topics. Additionally, it is suggested to develop digital-based STEM-PjBL learning media that can support more efficient implementation in various classroom environments.

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