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Comparing project-based learning and integrated STEM approach in enhancing scientific creativity in renewable energy education

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ABSTRACT

This quasi-experimental study investigates the effectiveness of project-based learning (PjBL) and its integrated science, technology, engineering, and mathematics (STEM) variant (PjBL-STEM) in enhancing scientific creativity among high school students. Conducted in an Indonesian senior high school, 69 tenth-grade students were assigned to an experimental group (PjBL-STEM, n = 36) and a control group (PjBL, n = 33) using a non-equivalent post-test-only design. A validated scientific creativity test (α = 0.79) was used to assess students' performance across fluency, flexibility, and originality dimensions. Findings revealed that students in the PjBL-STEM group scored significantly higher in overall scientific creativity, especially in generating original and technical solutions in renewable energy contexts. The PjBL-STEM model was shown to foster deeper engagement through problem-solving, project refinement, and critical evaluation processes. The study demonstrates that PjBL could be the way to implement integrated STEM education.

Keywords: alternative energy, creativity skills, integrated STEM, project-based learning

INTRODUCTION

In the 21st century, rapid technological advances and global competition demand a highly skilled workforce. STEM education is at the forefront of equipping individuals with the necessary competencies to thrive in this evolving landscape. Through STEM education, individuals can holistically improve their skills and knowledge in science, technology, engineering, and mathematics (STEM) (Kizhukarakkatu, 2025; Wahono et al., 2025). Integrating STEM into education can make a significant contribution to preparing human resources who are competent, adaptive, and ready to compete in the ever-evolving global job market (Alkhatib, 2025; Li et al., 2020).

One specific issue within this context is the development of scientific creativity among students. Creativity is an individual's ability to generate new ideas that are innovative and useful for solving problems or developing solutions in a particular context. Creativity can be divided into three domains: general, artistic, and scientific (Charyton & Snelbecker, 2007). This study will focus on one of them, namely, scientific creativity (Hu & Adey, 2002). According to Hu and Adey (2002) scientific creativity is an intellectual ability that allows a person to create original products of value based on previously known information. Liu et al. (2023) showed that individuals with high levels of scientific creativity tend to generate more innovative ideas in a scientific context.

Even though it is believed to be an essential competency, in some reports, student creativity is still relatively low, with no exception in Indonesia. According to the Martin Prosperity Institute's survey on the global creativity index 2015, Indonesia ranked 115th out of 139 countries (Florida et al., 2015). Moreover, the trends in international mathematics and science study conducted in 2019 revealed that Indonesia ranked 36th out of 39 participating countries for grade 8 mathematics and 38th out of 39 for grade 8 science (Mullis et al., 2019). These statistics underscore the need for educational institutions to pay more attention to facilitating creativity through their curriculum.

Various learning models have been proposed to address these challenges and enhance student interest and motivation in learning activities. Practical activities, for instance, can provide opportunities for students to construct knowledge based on factual information, an important aspect of scientific creativity (Siregar et al., 2022). The application of guided inquiry in science education has been proven to significantly increase student creativity by encouraging students to explore and solve problems independently (Ajwar et al., 2021). Other studies have also shown that informal science programs can effectively develop students' creativity (Orozco Gómez et al., 2021). These results are in line with recent findings showing that scientific creativity can thrive if supported by a collaborative and competitive academic atmosphere (Chen & Ma, 2025). These studies show how student activity and atmosphere in learning help in developing creativity.

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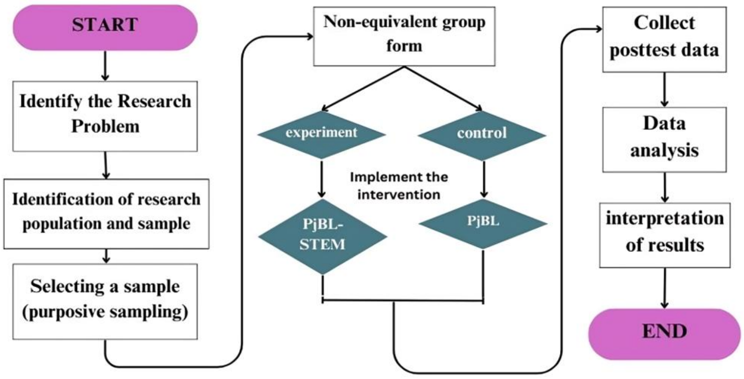


Figure 1. Flowchart of data collection procedures (Source: Authors' own elaboration)

One of the learning methods that is often referred to as a solution in developing student creativity is project-based learning (PjBL). Some studies have shown how PjBL can develop students' creativity (Chen et al., 2022; Li & Tu, 2024). PjBL encourages collaboration and real-world problem solving (Gutierrez-Berraondo et al., 2025), which is essential for developing creativity (Birdman et al., 2022). However, time constraints can sometimes be an obstacle. The long process of working on a project sometimes even makes students unable to reflect on their learning.

PjBL can also be implemented with an integrated STEM approach. This variant is known by the acronym PjBL-STEM. There is no consensus on the difference between PjBL and PjBL-STEM. However, we believe the two are different. PjBL-STEM differs from PjBL in that it integrates a multidisciplinary framework that emphasizes the interconnectedness of STEM fields to solve real-world problems. PjBL-STEM as a holistic approach not only enhances deep understanding of the subject matter, but also develops important skills such as creativity, critical thinking, collaboration, and innovation. This model has been shown to have a positive impact on students' scientific creativity (Karlina et al., 2023). Siew and Ambo (2018) found that a STEM-based project approach effectively improves students' scientific creativity. Utami and Nurlaela (2021) found that students showed greater interest in learning physics through the STEM learning approach compared to conventional methods. These results have also been recently confirmed by Zhang et al. (2025) projects carried out by students, which can facilitate the development of scientific creativity, especially in dimensions related to the products made by students. Although the impact is positive, its implementation is sometimes hampered by the high cost and difficulty of obtaining the resources needed to carry out the learning process.

Despite these findings, there is still a lack of research directly comparing the effectiveness of PjBL and PjBL-STEM learning models. Prajoko et al. (2023) concluded that the PjBL-STEM learning model has advantages in improving students' concept understanding and creativity compared to the conventional PjBL model because it can present a more holistic and in-depth learning experience for students. Moreover, according to Triprani et al. (2023) the application of PjBL-STEM learning, the use of alternative energy material is beneficial for students in learning the concept and meaning of alternative energy. Given that alternative energy is very important for life, it seems to be an ideal material to be studied in PjBL or PjBL-STEM learning.

This study aims to determine the effect of the PjBL-STEM learning model on students' scientific creativity in learning about alternative energy materials. Specifically, it seeks to compare the effectiveness of PjBL and PjBL-STEM models in enhancing students' scientific creativity skills.

METHODS

The study was conducted at one of the senior high schools in Bogor, Indonesia, which is under the auspices of the Ministry of Religious Affairs of the Republic of Indonesia with excellent accreditation and is known as one of the favorite schools in Bogor City in the even semester of the 2023/2024 academic year for three weeks with 3 hours per week. The participants involved 69 students, with 33 students in class X-2 as the control class and 36 students in class X-9 as the experimental class. This study used a quantitative approach, namely through the quasi-experiment method. The research design used in this study is a post-test only with a nonequivalent group design (Creswell, 2014). In this design, there are two groups, namely the experimental group (PjBL-STEM) and the control group (PjBL), which are not randomly selected using purposive sampling (**Figure 1**).

The independent variable in this study is the PjBL-STEM learning model, while the dependent variable is students' scientific creativity skills. The experimental class was conducted with three meetings applying the PjBL-STEM learning model according to Laboy-Rush (2011). In the first meeting, students are presented with a problem about the energy crisis and asked to give opinions related to the problem, followed by planning an alternative energy project model according to the groups that have been distributed. In the second meeting, students bring projects that have been made and then test, improve and collect output data on the project. In the last meeting, students present the results of observations on the projects of each group, and the teacher evaluates the projects produced by the students.

The control class used the PjBL learning model developed by two experts (Larmer, 2015). The syntax of PjBL follow Kemdikbud (2014). In the first meeting, the activities carried out were the same as the experimental class. However, in the second meeting, the difference was that students immediately presented the projects they had made without any activities to improve or calculate the output of the project. After the presentation, the teacher gave a learning evaluation. This was done based on interviews with

Table 1. Scientific creativity test scoring criteria

Scoring criteria	Skor	Item
Fluency (generate as many ideas/answers as possible)	Score 1 for each answer regardless of quality	1, 2, 3, 4, & 5
	Score 2 for each answer scheme regardless of quality	6
Flexibility (generate ideas based on different categories according to the number of approaches used)	Score 1 for each different approach	1, 2, 3, 4, & 5
	Maximum score: 4 points (scheme design: 1 point, evaluation method: 1 point, instrument: 1 point, and procedure: 1 point)	6
	Maximum score of 4 for each answer that displays more than two approaches correctly	7
Originality (producing unique ideas that rarely appear in answers)	Answers are tabulated based on the frequency of all answers from all students, and the probability of each answer is calculated. Score 3 points if the probability of each answer is < 5%, 2 points if between 5%-10%, and 1 point if > 10%	1, 2, 3, 4, 5, 6, & 7

Table 2. Categories of scientific creativity

Cluster	Category	Value
1	Low	< 69
2	Medium	70-90
3	High	> 91

Table 3. Descriptive statistics of scientific creativity

Class	N	Minimum	Maximum	M	SD
Experiment class	36	66	98	78.53	7.955
Control class	33	56	89	72.42	8.739

teachers at the research location and adjusted to the learning model that the teacher had prepared. After the treatment, students were given a post-test in both classes to measure their scientific creativity skills in alternative energy material.

The study's data was obtained using a scientific skills test instrument developed by Hu and Adey (2002). This model is based on cognitive aspects that form the science structure creativity model structure. This structure is built with 24 cells, and each cell has three dimensions, namely the process, trait, and product dimensions. This scientific creativity indicator consists of seven scientific creativity indicator items to show students' ability in terms of fluency, flexibility, and originality.

The test instrument was organized according to the dimensions of scientific creativity and applied to 76 high school students and three physicists to determine whether the instrument measured scientific creativity. Validity and reliability test calculations were carried out to ensure the instrument was valid and reliable. Validity test calculations with the Pearson product-moment correlation formula found that all seven questions of the scientific creativity test instrument were considered valid (Morgan et al., 2012). The reliability test is acceptable with an alpha Cronbach's value of 0.79.

The students' scientific creativity test instrument uses the assessment criteria as shown in **Table 1**.

Data analysis was performed with descriptive and inferential statistics. Descriptive statistical analysis was conducted to describe the research data, including the amount of data, maximum and minimum values, standard deviation (SD) and mean (M). The scores obtained were then presented in percentage form. The grouping of scientific creativity scores was divided into three clusters using the cluster analysis method, namely non-hierarchical cluster analysis (k-means cluster). The scientific creativity categories are presented in **Table 2**.

Inferential analysis was conducted by first testing the normality and homogeneity of the data. Shapiro-Wilk normality test and homogeneity test with Levene's test ($p > 0.05$). Data analysis uses parametric statistics because the research data is normally distributed. In this research, data analysis was done using the independent sample t-test parametric test to determine the significant difference in the average between the experimental class with the PjBL-STEM model and the control class with the PjBL model.

Then, to test the answer to the average scientific creativity score based on seven indicators and subdimensions, the researcher wrote the provisions for the experimental class with the letter "E" and for the control class with the letter "C" followed by a "number" based on the student's serial number.

RESULTS

The results of descriptive statistical analysis of the experimental and control classes are presented to show how PjBL and PjBL-STEM can influence students' scientific creativity. The description of both classes can be seen in **Table 3**.

Table 3 shows the creativity score of the experimental class (maximum = 98; minimum = 66) and the control class (maximum = 89; minimum = 56). There is a difference between the creativity value of the experimental class (M = 78.53; SD = 7.95) higher than the control class (M = 72.42; SD = 8.74). The difference in average results indicates the influence of the PjBL-STEM learning model on scientific creativity.

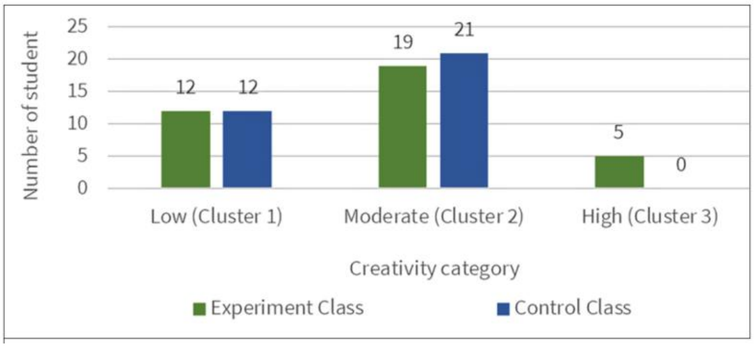


Figure 2. Results of students' scientific creativity (Source: Authors' own elaboration)

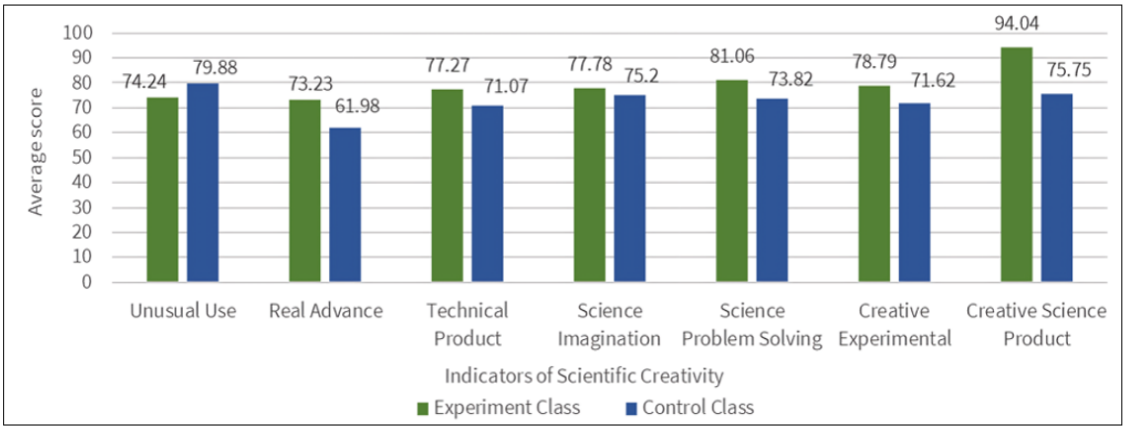


Figure 3. Average post-test results per indicator (Source: Authors' own elaboration)

Figure 2 presents the categories of students' scientific creativity levels based on the creativity scores obtained by students in the experimental and control classes. The results indicate that the majority of students are in the medium creativity category (cluster 2), with 19 students representing 57.78% of the total students in the experimental class and 21 students representing 63.64% of the total students in the control class. A total of five students from the experimental class were classified as highly creative (cluster 3), representing 13.89% of the total students. Conversely, 12 students were classified as low creative (cluster 1), representing 33.33% of the total experimental class students, and 12 students were classified as low creative (cluster 1), representing 36.36% of the total control class students. This result indicates that the assessment of scientific creativity based on the categories presented in **Table 2** is included in the moderate category.

Of the seven indicators, there are six indicators where the scientific creativity score in the experimental class is higher than the control class, namely the real advance indicator (M_E = 73.23; M_C = 61.98), technical product (M_E = 77.27; M_C = 71.07) $M_E = 77,27; M_C = 71,07$, science imagination (M_E = 77.78; M_C = 75.20), science problem solving (M_E = 81.06; M_C = 73.82), creative experimental (M_E = 78.79; M_C = 71.62), creative science product (M_E = 94.04; M_C = 75.75). One other indicator that shows the scientific creativity score of the control class is higher than the experimental class is the unusual use indicator (M_E = 74.24; M_C = 79.88). This is because, in the unusual use indicator control class, students predominantly have the ability to apply unusual uses or provide unique answers compared to those in the experimental class. Example of student answers on the unusual use indicator:

(a) student E6 mentioned four answers, one of which was to make solar LED lights and

(b) student C28 mentioned four answers, one of which was to make a solar-powered speed-measuring device (**Figure 3**).

Based on the three dimensions of scientific creativity, namely the process, trait, and product dimensions. The trait dimension was chosen as the assessment reference with the sub-dimensions of fluency, flexibility, and originality.

Figure 4 the average score of fluency (M_E = 68.63; M_C = 64.52), flexibility (M_E = 82.73; M_C = 74.89), and originality (M_E = 84.79; M_C = 78.78). Based on the three sub-dimensions, the average value in the experimental class is higher than in the control class. This shows that learning with PjBL-STEM significantly affects the three sub-dimensions of scientific creativity.

Before starting the hypothesis test, the first step is to test the assumptions involving the normality test of the data distribution and the variance homogeneity test as a prerequisite test. The normality test was conducted using Shapiro-Wilk statistics (Field, 2017).

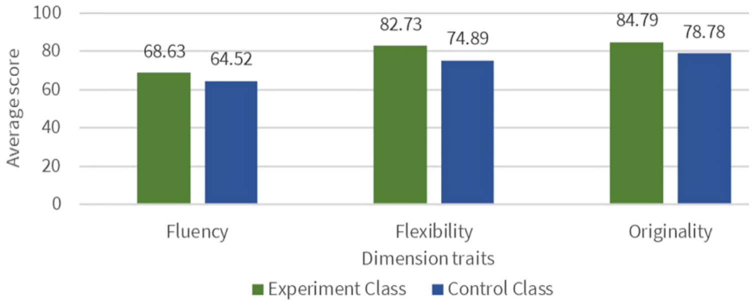
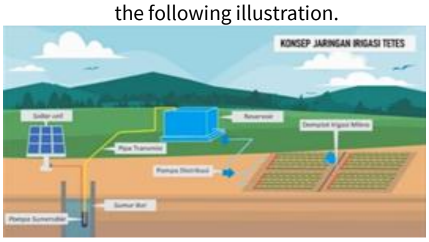


Figure 4. Average post-test results per sub-dimension (Source: Authors' own elaboration)

Table 4. Normality test for scientific creativity

Class	Shapiro-Wilk		
	Statistic	df	Significance
Experiment class	.960	36	.221
Control class	.978	33	.724

Table 5. Examples of student answers in the fluency dimension

SCI	Question	Experiment class	Control class
Real advance	Your school is organizing a visit to a village. When you visit the village, you are invited to see the smart irrigation system used by the villagers using the drip irrigation method, as shown in the following illustration.  If you are asked to modify the irrigation system to optimize its use to increase the efficiency of irrigated rice fields while reducing energy consumption, write down as many deas/innovations as you can think of! For example, applications and artificial intelligence (AI) to assist in the management and monitoring of irrigation systems, such as analyzing data from various sensors, weather, and crop growth patterns to automatically adjust the irrigation schedule.	Student E23: "Make a battery to store the energy that has been generated so that it can be used at night/solar panels are not working, make technology on solar panels that can follow the direction of the sun throughout the day so that the energy produced is maximized, make water irrigation from the nearest ditch/river to the water tank to anticipate if later the water from the well runs out, make a system that can be controlled manually/automatically for the release of water from the water tank when it rains so that the plants are not overwatered and can adjust the water intensity."	C3 students: "Using AI and IoT technology to remotely monitor and control irrigation systems, using precision irrigation systems that can manually adjust the amount & time of watering, using vertical irrigation systems that can reduce the area that needs to be watered, using terrace irrigation that can reduce soil erosion & increase irrigation efficiency."

Note. SCI: Scientific creativity indicator

The normality test results showed that the data were normally distributed ($p > 0.05$), and the analysis was carried out using the independent sample t-test test (**Table 4**). The average score between experimental class students ($M = 78.53$; $SD = 7.95$) and control class ($M = 72.42$; $SD = 8.74$). Based on the independent sample t-test test analysis, the sig value (2-tailed) = 0.003 in the experimental class and 0.004 in the control class. This indicates that the null hypothesis (H_0) is rejected, and the alternative hypothesis (H_a) is accepted. So, it can be said that there is a statistically significant difference between the average scientific creativity of students in the experimental class and the control class.

The next analysis is to analyze the results of students' post-test answers. The fluency sub-dimension is determined based on as many ideas/answers as possible from students (Hu & Adey, 2002). The average fluency score did not show a high difference between the experimental and control classes. The analysis of students' answers showed that in each class, students wrote more than 3 or 4 items. In the control class, students tended to repeat the answers that had been exemplified in the questions. Examples of student answers from experimental and control classes are in **Table 5**.

Furthermore, the flexibility sub-dimension is determined based on different categories according to the number of approaches used in student answers. The average score on the flexibility sub-dimension is higher than the average fluency sub-dimension. Students in the experimental class were more able to describe answers by taking different approaches to a problem based on different points of view and more detailed reasons. In the control class, some wrote answers without reason. Examples of answers from experimental and control classes (**Table 6**).

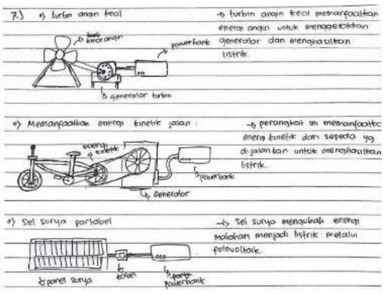
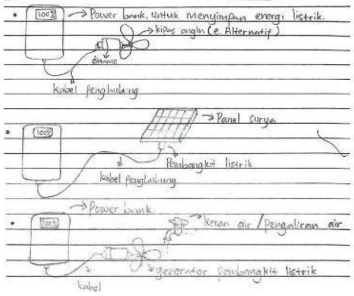
The original sub-dimension is determined based on answers or solutions that rarely or only appear occasionally in all populations of answers. In the experimental class, students were more able to describe the design in an original way with the addition of brief explanations related to factors such as safety and efficiency of the design they made. In contrast, the answers in the control class were dominated by drawings without descriptions such as safety and design efficiency, which are examples of answers from experimental and control classes (**Table 7**).

Table 6. Example of student answers on flexibility dimension

SCI	Question	Experiment class	Control class
Technical product	In physics, you are given the task of repairing an ordinary wind turbine provided by your school. If you are asked to design an improvement, please think of as many improvements as possible to the ordinary wind turbine to make it more interesting and more useful. For example, blades can be designed with a more efficient aerodynamic shape to capture more wind energy.	Student E25: "Make the fan dimensions adjust to the wind conditions so that the turbine can rotate faster, change the fan material to be lighter, add solar panels to the turbine for greater energy, attractive and innovative aesthetic design."	Student C15: "Using turbine cooling system to prevent overheating, using lightweight materials, using low wind speed, larger rotor diameter."

Note. SCI: Scientific creativity indicator

Table 7. Example of originality dimension student answers

SCI	Question	Experiment class	Control class
Creative science product	You are a high school student interested in developing a science project on the use of one of the alternative energies in making power banks. You want to design a device that can convert one of the alternative energies into electricity that can be used to charge cell phones in the form of a power bank. Draw three designs for a power bank device that utilizes alternative energy effectively and is environmentally friendly. Make sure each design considers factors such as the safety and efficiency of the alternative energy.	Student E7  Description: -Small wind turbine (utilizes wind energy to drive a generator and generate electricity. -Harnessing the kinetic energy of the road (this device utilizes the kinetic energy of a running bicycle to generate electricity. -Portable solar cells (solar cells convert solar energy into electricity through photovoltaics) Student E34  Description: -Utilizes water currents to use a water turbine that can generate electrical energy and store it in a battery that is connected via a cable and located inside the box so that the power bank is not too exposed to splashing water and becomes a place for the device to be charged. -Between the solar panel and the battery located inside, there is a special iron plate connected to the water container next to the power bank so that the heat from the solar panel does not damage the battery and the components inside to distribute the heat to the water which can be replaced if the water is getting hot. -There is a frame to hold the power bank so that it does not fall.	Student C6  Description: -Powerbank to store electrical energy from fans and dynamos -Power bank from solar panels -Power bank from water taps/water supply Student C32  Description: - Wind energy power bank (windmill to charge the power bank) - Heat energy power bank (heat absorption) - Motion energy power bank (Motion handle generates electricity)

Note. SCI: Scientific creativity indicator

DISCUSSION

This study analyzed the impact of the PjBL-STEM learning model on scientific creativity and alternative energy. The findings showed that the PjBL-STEM learning model significantly affected scientific creativity skills. The results of this study are in accordance with the findings of several previous studies. Abdurrahman et al. (2023) investigated the learning model integrated with STEM as providing an effective learning atmosphere where students can further explore the knowledge and context of renewable energy. The STEM approach to learning provides the necessary stimulus for educators to develop students' scientific creativity (Diep et al., 2023). Other research states that the STEM approach is very beneficial for prospective educators in improving scientific creativity skills. Through this hands-on experience, prospective educators can develop their creativity skills in designing interesting learning experiences (Domenici, 2023). PjBL-STEM has a positive influence on increasing student creativity through product design to solve real-world problems (Baran et al., 2021).

Students' scientific creativity in the experimental class was higher than in the control class, presumably due to students' involvement in investigation, design, decision-making, and problem-solving activities (Barak, 2020). In the process of making projects, students are free to choose what projects they want to make. One of the projects made in the experimental class was making waterwheels and windmills. By providing opportunities for students to work on projects of their interest it can increase scientific creativity (Insyasiska et al., 2015). Educational activities that permit students to design and manufacture products, particularly in a context related to STEM, have been demonstrated to enhance students' scientific creativity abilities (Lidya et al., 2024). Learning models that implement STEM education also help students to be better prepared for global challenges, such as resource, health, and energy crises, by preparing them to contribute to the development of innovative technologies and solutions (Kurniati et al., 2022).

In doing this project, students are guided to design a product from the stages in the worksheet. The design of this tool is based on the ideas of the students themselves by creating innovative ideas and solutions to these challenges through practical and directed application of their knowledge and skills (Hsu & Van Dyke, 2021). It can be said that in experimental class activities, students are always faced with new situations that make students show an investigative attitude so as to encourage students to play an active role by expressing opinions, ideas, and questions during learning (Primadhini, 2021; Qalbina et al., 2023). Students especially use their imagination when describing improvements to the project design, which in this situation contributes to their scientific creativity skills (Dogan & Kahraman, 2021). In addition, the reason for the increase in scores on the fluency, flexibility, and originality sub-dimensions of experimental students is higher than in the control class, which may be due to project evaluation activities that are oriented towards project trials by analyzing deficiencies in the project and improving the design to make it better so that students constantly get different perspectives on projects that produce new and original products that improve their creativity and learning outcomes (Lestari et al., 2022). In the end, students produce creative products on alternative energy materials, which can be said that the processes in STEM-based PjBL contribute to students' scientific creativity.

CONCLUSION

The results of the study showed that the PjBL-STEM learning model has a significant positive effect in improving students' scientific creativity skills compared to the PjBL learning model with alternative energy material, in a moderate category. This is indicated by the significance value of the independent sample t-test of 0.003. Data analysis based on sub-dimensions shows that the fluency, flexibility, and originality scores of the experimental class are greater than those of the control class. Thus, the PjBL-STEM learning model can be an effective learning strategy to implement integrated STEM education and improve students' scientific creativity.

Further research is needed to integrate STEM into physics learning. As for some suggestions made by researchers to improve the generalization of results, namely forming more experimental and control groups, based on larger participants, and using a wider range of learning materials and over a longer period of time.

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Ethical statement: The authors stated that the study involved high school students in a standard educational setting and did not collect any sensitive personal or health-related data. Ethical approval was not required as per the guidelines of the UIN Syarif Hidayatullah Jakarta in educational contexts. The authors further stated that, prior to data collection, informed consent was obtained from all participating students and their legal guardians. Anonymity and confidentiality of the participants were maintained throughout the study, and all data were used solely for research purposes.

AI statement: The authors stated that generative AI tools were employed in the preparation of this article for specific purposes. Scopus AI assisted in identifying relevant literature, with all references provided by the tool being thoroughly reviewed and verified. Additionally, ChatGPT was used to translate and refine the manuscript into academic English, ensuring clarity and proper scholarly language. An example of the prompt used in ChatGPT for translation and refinement is as follows: 'Please translate the following passage into academic English, ensuring the language is clear, formal, and suitable for a scientific journal.' The final draft was then read and discussed by all authors before submission.

Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from the corresponding author.

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