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The effect of design-based STEM learning on students' scientific creativity in solar energy topic

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Abstract: This study aims to investigate the effect of design-based STEM learning on students' scientific creativity in the context of solar energy. The study involved 64 tenth-grade students from a public Madrasah Aliyah in Jakarta, who were split into two groups: an experimental group that used design-based STEM learning and a control group that used conventional learning. Both groups were given a scientific creativity posttest in the form of seven open-ended questions. The study results showed that the experimental group's average scientific creativity score was higher than the control group's. Furthermore, the subdimensions analysis revealed that the experimental group's flexibility and originality significantly affected their scientific creativity. The study shows that design-based STEM learning positively impacts students' scientific creativity in the context of solar energy, although with a low category. This research can be a reference for future research to investigate the influence of design-based STEM learning on students' scientific creativity in various contexts.
Keywords: design-based STEM; scientific creativity; solar energy

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Introduction

Science, Technology, Engineering, and Mathematics (STEM) Education has an essential role in the progress of a nation, one of which is developing 21st-century skills. This has led to an increased focus on STEM education in many countries, including the United States (Hathcock et al., 2015), Japan (Saito et al., 2015), Turkey (Ong et al., 2016), and Iran (Shahbazloo & Abdullah Mirzaie, 2023). STEM education is an interdisciplinary approach to acquiring knowledge and skills through experiences in real-world contexts (Lamb et al., 2015). This interdisciplinary approach allows students to solve real-world problems and emphasizes developing 21st-century skills (Bybee, 2010). To improve student competence, innovations in STEM education need to be made by combining STEM learning with other learning methods, such as Problem-Based Learning (Lou et al., 2011), Inquiry-Based Learning (Yuliati et al., 2018), Project-Based Learning (Purwaningsih et al., 2020), and Phenomenon-Based Learning (Suryadi et al., 2021).

Design-based learning is one of the strategies to implement an integrated STEM education approach. STEM education is based on constructivism and constructionism theories that emphasize the role of design in facilitating knowledge construction (Suryadi & Kurniati, 2021), while design-based learning is a learning method that uses design to evaluate student understanding (Azizan & Abu Shamsi, 2022). Design-based STEM learning is understood as a process of learning in which students use science, math, technology and engineering knowledge to develop creative systems, processes or products that will meet specific needs through the design process (Dym et al., 2005; English, 2020). This learning is dynamic and responsive, with iterative phases that can facilitate the full integration of all four STEM disciplines (Cheng & So, 2020). Design-based STEM learning aims to enhance 21st-century skills (Eroğlu & Bektaş, 2022), one of which is creativity (Li et al., 2019).

Creativity is one of the most critical skills for students in the 21st century. Creativity plays an essential role in problem-solving (Runco, 2004), inquiry skills, and engineering design (Christiaans & Venselaar, 2005). Furthermore, creativity can be a cornerstone of Education in sustainable development that allows students to make the most of their experiences (Tatlah et al., 2012). Despite this, there is a striking paradox: many teachers neglect students' creativity (Runco, 2004; Sternberg, 2003). One type of creativity essential to developing students' competence is scientific creativity. Specific to science education (Hu & Adey, 2002; Sidek et al., 2020), this creativity is separate from general creativity (Mukhopadhyay, 2013). Scientific creativity is the ability to generate original ideas or products that involve the interaction between general creativity, scientific skills, and scientific knowledge (Sak & Ayas, 2013).

Many researchers have explored the positive effects of STEM learning on creativity, particularly in science. Research by Hanif et al. (2019) found that project-based learning STEM positively impacted scientific creativity related to light and optics. In their study, 25 eighth-grade students worked in groups to create mini-projectors. The final product was assessed based on the creativity dimensions of resolution, elaboration, and novelty; 76% of the final product was categorized as good. In another study, Tran et al. (2021) assessed the creativity of 63 junior high school students after designing an ancient mechanical clock with the concept of gears for four weeks. The results showed a significant change in students' creativity scores before and after the activity. A study was conducted on 133 grade 9 students from a large urban city in Turkey. The study reported that STEM learning applied to the nature of science and creativity improved academic achievement, scientific creativity, and outlook. More recently, Wan et al. (2023) conducted a study in Hong Kong examining the impact of design-based STEM learning on primary school students' creativity. The study significantly increased STEM creativity's fluency and flexibility dimensions. However, there is a lack of relevant studies on solar energy.

Solar energy is a topic that students study in school. Renewable energy, including solar energy, is one of the targets of Environmentally Sustainable Development (ESD) (UNESCO, 2018). Thus, the topic of solar energy in physics learning is important because students will play a major role in the future of renewable energy technology (Sulaiman et al., 2023). Indonesia's location and climate are factors for studying solar energy, including in STEM learning (Grubbs & Deck, 2015). A study in Iran showed that STEM education in the context of solar energy significantly increased students' creativity (Shahbazloo & Abdullah Mirzaie, 2023). The study was conducted on 143 female students over seven distance learning sessions. Another study reported that creative products through STEM integration supported student creativity in 29 students in an applied science course (Mayasari et al., 2016).

Despite this, research on the topic of solar energy is still limited. The scarcity of reading materials, such as textbooks and reference books, is a challenge for students to understand the topic of solar energy in learning (Chien et al., 2021). The lack of equipment during learning makes it difficult for students to practice their knowledge (Putri et al., 2020). Research by (Vilmala et al., 2023) shows that renewable energy questions have the lowest score on the measurement of cognitive aspects of the energy theme, which is only 30% of students who answer correctly. Furthermore, the study's results stated that learning for Environmentally Sustainable Development (ESD), which involves making products, gives students experience in solving various environmental-related problems. Therefore, the researcher will conduct research by applying design-based STEM to make creative products, namely automatic garden lights. This study aims to determine the effect of design-based STEM learning on student creativity in solar energy.

Method

Type of Research

This quantitative research is quasi-experimental with a posttest-only design (Cresswell, 2023). This study involved two groups that were randomly assigned as experimental and control groups. The school had formed the groups, so the researcher could not change the students in each group. In this study, the intervention with design-based STEM learning was given to the experimental group. As a comparison group, the control group did not receive treatment to ensure that any differences between the two groups were only caused by the intervention and not other factors. The research design is given in Table 1.

Table 1. Posttest-Only Group Design

Group	Treatment	Posttest
Experiment	X	O_1
Control		O_2

With X is the treatment given in the experimental group, namely design-based STEM learning, O_1 is the final test (posttest) given to the experimental group, and O_2 2 is the final test (posttest) given to the control group.

Research participant

This research was conducted in one of the Madrasahs in Jakarta, Indonesia. The research was conducted from October to December 2023. The population of this study was all tenth-grade students in the odd semester of the 2023/2024 school year, totalling 244 students. The participants of this study consisted of 64 tenth-grade students, 36 students in class X-B as the experimental group and 28 students in class X-G as the control group. Both classes are in the same school, with class placement determined randomly by the school. So, it can be assumed that the initial conditions of the two groups are the same. The experimental and control groups were given the scientific creativity test as a posttest.

Instrument

The scientific creativity test instrument was adopted from the Scientific Structure Creativity Model (SSCM) developed by Hu and Adey (2002). The three dimensions of the SSCM model consist of 24 cells, namely 4 product dimensions x 3 trait dimensions x 2 process dimensions (Chin & Siew, 2015). The question items were organized based on the three dimensions of SSCM. The test instrument consisted of seven open-ended question items used to measure fluency, flexibility, and originality.

Physics education experts checked the research instruments used to determine whether they measured scientific creativity. A pilot test of the instruments was conducted with twelfth-grade students as participants. Validity and reliability calculations were undertaken to ensure the instruments were valid and reliable. Calculation of the validation test using the Pearson product-moment technique reported seven questions of scientific creativity are valid and can be used. Furthermore, the reliability test was carried out using the Cronbach alpha formula (*Alpha* = 0.83), which stated that the question instrument had very high reliability.

There is an element of subjectivity in interpreting the scoring rules, so researchers check the scoring system on each indicator. Two raters independently tested the scientific creativity scoring rules on 30 students. One rater was unrelated to the research study, and the other was the principal investigator. The inter-rater agreement among the experts varied from 0.571 (moderate) to 0.883 (almost perfect), with an average of 0.754 (substantial) based on the interpretation (Landis & Koch, 1977). The inter-rater results on each indicator are shown in Table 2.

Table 2. Inter-rater Results between Two Raters

Item	Score Agreement (n = 30 answer sheets)	
1	*Unusual Use (UU)*	0.740
2	*Real Advance (RA)*	0.812
3	*Technical Production (TP)*	0.571
4	*Science Imagination (SI)*	0.628
5	*Science Problem Solving (SPS)*	0.770
6	*Creative Experimental (CE)*	0.877
7	*Science Product (SP)*	0.883

Research Procedure

This study was conducted for four weeks, 2 hours per week. Before implementation, the researcher conducted a brief interview with the teacher on-site. The researcher identified the processes and activities to be implemented in the experimental and control groups. Teachers in both groups are the same person, and they have a master's degree in science education but have never implemented design-based STEM in learning. Before the study started, the researcher observed the teaching of both groups with the same lesson and teacher. This was done to ensure the lesson was implemented appropriately for each group. The lesson was designed using Design Based STEM phases in the experimental group and 5E phases in the control group. Both groups made projects related to alternative energy with different lessons.

The research procedure consisted of three stages. The first stage, preparation, involves preliminary studies that include observations, interviews, and literature searches related to design-based STEM learning and scientific creativity abilities, followed by formulating problems based on the findings. Then, researchers compiled test instruments, teaching modules, and LKPD, accompanied by validation by experts and lecturers. The second stage is the research implementation stage; researchers provide learning treatment using design-based STEM in the experimental group. Design-based STEM learning in this study focuses on the topic of solar energy. Students carried out activities with the help of STEM worksheets and the STEM KIT that had been developed. The design-based STEM activities (Wheeler et al., 2014) carried out by students in this activity are shown in Table 3.

Table 3. Design-based STEM Activities for Each Step

Meeting	Steps Design-Based STEM	Activities
1	Brainstorming	Students identify problems and solutions related to alternative energy
	Research	Students search for information about renewable energy Students discuss the tools and materials to be used Students find information about solar panels (the main component of the product) through simple experiments
2	Design	Students create an automatic light product design Students make an automatic lamp frame based on the design made
3	Construction and Testing	Students make an automatic light circuit. Students make automatic lights based on the design drawings Students test their products
4	Evaluating	Groups present their products and the basic concept behind the product The teacher gives an evaluation of the students' products Students conduct peer evaluations of other groups' products
	Redesign	Students redesign the product based on feedback and suggestions

In the control group, conventional learning was conducted. Conventional learning was performed using the 5E method. This was based on results from teacher interviews at the research site and adjusted to the teaching module the teacher had prepared. Learning was carried out with almost the same steps as in the experimental group; the task of making alternative energy products was also given in the control group. The difference is that in the experimental group, product making is carried out through learning and is equalized for one group, namely, making automatic garden lights with solar panels. While in the experimental group, students made products outside of learning and were free to choose alternative energy sources for the products they made. In addition, the control group did not have a design process.

After completing the learning, both groups were given a posttest to measure the students' scientific creativity ability. The final stage involved data analysis of the research results, hypothesis testing to determine the effect of design-based STEM on students' scientific creativity skills, and concluding the analysis and hypothesis testing results.

Data analysis

Students' scientific creativity test results were scored based on the scientific creativity test scoring guidelines by modifying Hu and Adey (2002) presented in Table 4.

Table 4. Scoring guidelines for scientific creativity test

Item	Sub-dimension	Scoring guidelines
1, 2, 3, 4, 5	Fluency	Count every answer given by the students, regardless of its quality. Each answer is given a score of 1
	Flexibility	Count each answer from a different perspective/number of approaches that differ from the student's answer. Each of the different approaches is given a score of 1
	Originality	Tabulate the frequency of all answers obtained. The frequency and percentage of each answer are calculated: - Student's answers: <5% of all student's answers gave a score of 2. - Student's answers were 5–10% of the answers all students gave, then given a score of 1. - Students' answers > 10% of all students' answers gave a score of 0.
6	Fluency	Count every answer given by students, regardless of quality. Each circuit scheme is given a score of 2
	Flexibility	Scores are obtained by awarding points 1-3 based on the different viewpoints or number of approaches used in the student's answer.
	Originality	The Probability less than 5% scores 3 Probability: 5-10% scores 2 The Probability of more than 10% getting a score of 1
7	Flexibility	The score is obtained by giving 2 points for each design criterion mentioned by students.
	Originality	Scores are obtained by giving points 1–5 according to the diversity and suitability of student answers in the form of images provided

*ideal score = 75

Based on Table 4, the score is converted into a scientific creativity value obtained from the total score divided by the ideal score multiplied by 100. The value of creativity is divided into four categories (Prajoko et al., 2023), presented in Table 5.

Table 5. Categorization of Scientific Creativity Score

The Score of Scientific Creativity	Criteria
86 < M ≤ 100	Very creative
70 < M ≤ 86	Creative
60 < M ≤ 70	Moderate

The Score of Scientific Creativity	Criteria
40 < M ≤ 60	Less
M ≤ 40	Poor

Descriptive statistics of scientific creativity were calculated for the mean, standard deviation, and median. Data collected from the scientific creativity test were analyzed using the Shapiro-Wilks normality test and homogeneity test with Levene's test ($p > 0.05$). Data analysis in both groups used parametric tests because the data fulfilled the assumptions of parametric tests.

In this study, data analysis used the parametric Independent Sample t-test to test the difference between the two groups regarding scientific creativity. The test was conducted to determine whether there was a significant effect on Design-Based STEM learning in the experimental group. Effect Size test was conducted to determine the amount of influence in a study caused by independent or group variables. The eta squared value on the scientific creativity score was calculated to determine the difference in size between the two groups (Field, 2009).

Then, the written answers to the open-ended questions were analyzed using the interpretive method (Erickson, 1985) to explore the general ideas that emerged from the 64 participants' statements. The researcher wrote down the coding; the groups were coded with the letter "E" for the experimental group and "C" for the control group, followed by a "number" representing the sequential number of students in the group.

Results and Discussion

This study assessed scientific creativity test scores based on the test scoring guidelines modified by Hu and Adey (2002). The scientific creativity scores of the experimental and control groups after treatment are presented in Table 6.

Table 6. Scientific Creativity Test Scores of Experimental and Control Groups

Data	Control Groups	Experiment Groups
N	28.00	36.00
Max	75.33	82.67
Min	29.33	32.67
Mean	58.92	64.24
Median	61.33	65.00
St.Dev	10.30	10.13

Table 6 shows the creativity scores of the experimental group (Max = 82.67; Min = 32.67) and the control group (Max = 82.67; Min = 32.67). The experimental group's mean value of scientific creativity (M = 64.24; sd = 10.13) was higher than the control group (M = 58.92; sd = 10.30). Based on Table 5, the value of scientific creativity was classified as moderate in the experimental group and less so in the control group. These results indicate the effect of design-based STEM learning on students' scientific creativity.

The results of this study measured students' scientific creativity based on seven indicators. The scientific creativity scores between the experimental and control groups were compared based on the indicators, and the results are shown in Figure 1. Five of the seven indicators showed higher mean scores for the experiment group than the control group. The five indicators include unusual use (M_E = 77.50; M_C = 72.50), real advance (M_E = 80.28; M_C = 71.78), science imagination (M_E = 63.61; M_C = 56.70), creative experimental (M_E = 49.07; M_C = 40.47), and science product (M_E = 55.98; M_C = 42.85). Meanwhile, the technical production indicator (M_E = 68.88; M_C = 71.42) and science problem solving (M_E = 59.86; M_C = 65.89) show that the control group's mean score is higher than the experimental group.

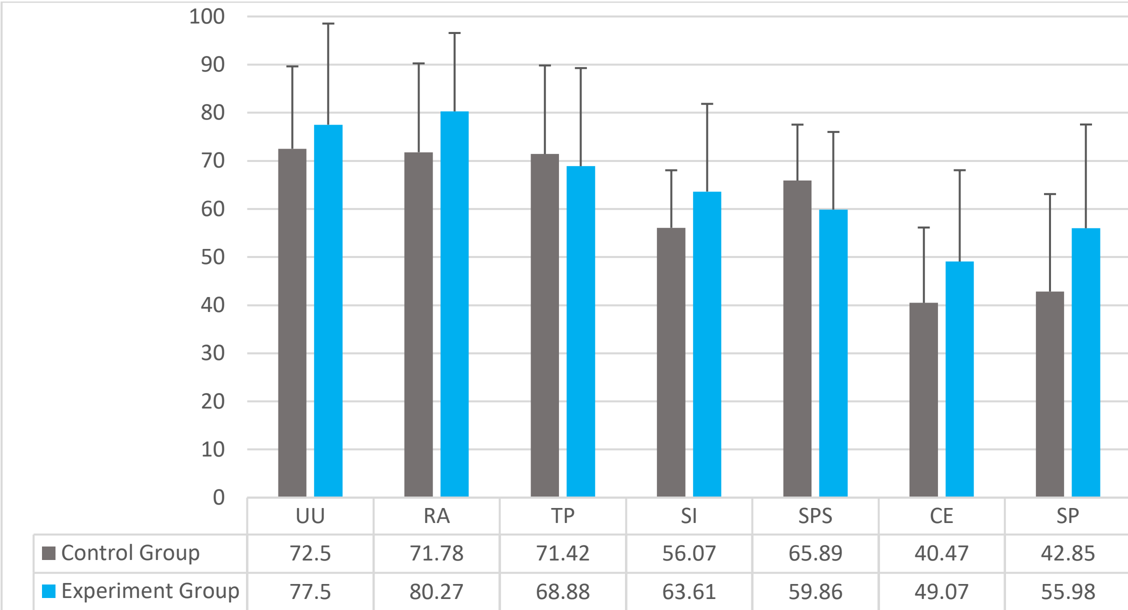


Figure 1. Average scientific creativity score based on seven indicators

*unusual use (UU), real advance (RA), technical production (TP), science imagination (SI), science problem solving (SPS), creative experimental (CE), and science product (SP).

Of the three dimensions of scientific creativity, the trait dimension was chosen as the basis for scoring with the sub-dimensions of fluency, flexibility, and originality. The experimental and control group students' scientific creativity findings were based on the fluency, flexibility, and originality sub-dimension scores. The results are presented in Figure 2.

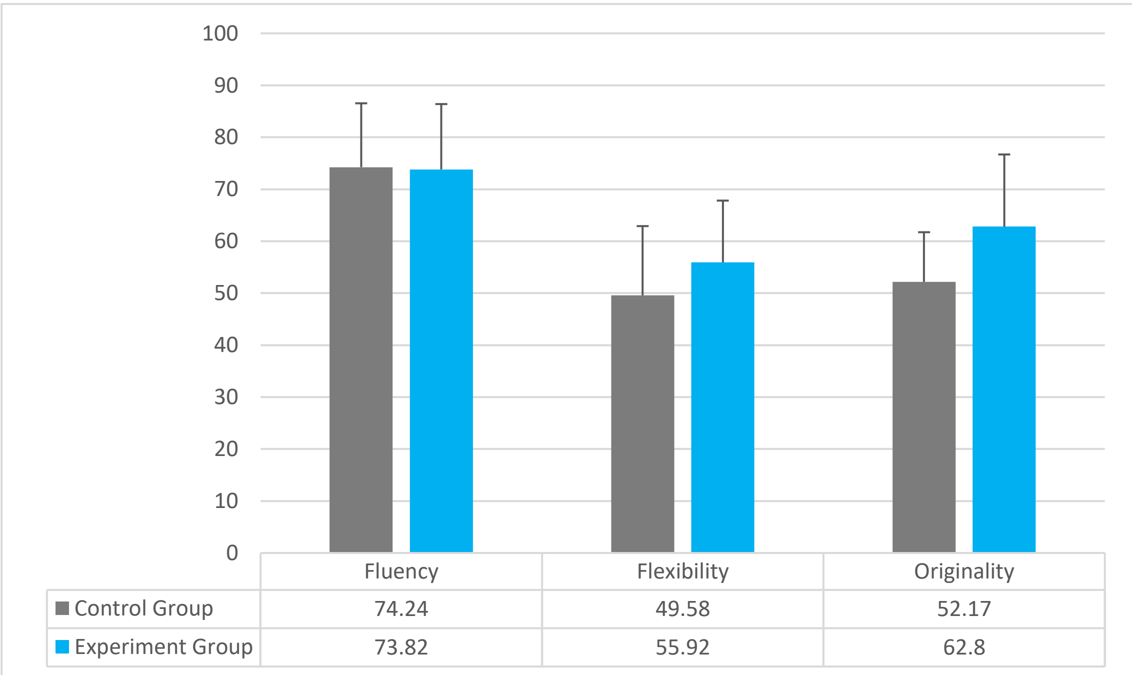


Figure 2. Average scientific creativity score based on the score

Figure 2 shows that in the fluency score, both groups scored higher than the flexibility and originality scores. Although the mean of the control group (M_C = 74.24) was higher than that of the experimental group (M_E = 73.82), with a very small difference, both groups could write answers fluently.

The experimental group's flexibility score (M_E = 55.92) was higher than the control group (M_C = 49.58). This score is the lowest compared to both groups' fluency and originality scores. This shows that students are less able to write ideas from various approaches. The results also show originality is the score with the most significant average difference between the experimental group (M_E = 62.80) and the control group (M_C = 52.17). This means that design-based STEM learning significantly affects the originality score.

Inferential statistical tests followed the difference in scientific creativity scores between the two groups. Before the inferential statistical test, the assumption test was conducted with the normality and homogeneity tests. The results of the normality test are shown in Table 7.

Table 7. Normality Test Results

Group	Shapiro-Wilk		
	Statistic	df	Sig.
Experiment	.955	36	.150
Control	.949	28	.182

Based on the results of the analysis with Independent T-Test, the scientific creativity scores between the experimental group students ($M = 64.24$; $sd = 10.1$differente control group ($M = 58.92$; $sd = 10.30$) were significantly different ($t\,(62) = 2.065, p < 0.05$). These results indicate that the experimental group's design-based STEM learning significantly affects students' scientific creativity.

The significant effect of Design Based STEM on scientific creativity was followed up with the effect size test. The test was conducted to determine the magnitude of the impact of the treatment in the study. In this study, the eta-square value of the scientific creativity variable was obtained at 0.254. Based on the effect size interpretation table, the effect of the treatment on scientific creativity is in the small category (Field, 2009).

Then, students' scientific creativity scores based on fluency, flexibility, and originality were also analyzed with Independent T-Test to determine if there was a significant difference between the two groups. The results are shown in Table 8.

Table 8. Independent Samples Test Results of Scientific Creativity

Score	t	p
Fluency	0.134	0.894
Flexibility	2.007	0.049
Originality	3.458	0.001

Table 8 shows that there is a significant difference between the scientific creativity of the experimental and control groups, namely on the flexibility score ($t\,(62) = 2.007$, $p < 0.05$) and originality (($t\,(62) = 3.458$, $p < 0.05$). Meanwhile, the fluency score showed no significant difference between the two groups.

Analysis was also conducted by observing students' test answer sheets. The fluency score is determined by the number of original answers produced (Hu & Adey, 2002). The research showed that students in the experimental group tended to limit their answers to 3 or 4 items. Meanwhile, students in the control group were more fluent in writing many answers. Examples of student responses from both groups are presented in Table 9.

Table 9. Examples of Student Answers in The Fluency Sub-dimension

Indicator	Question	Control Group	Experimental Group
Unusual Use	During the physics lesson on renewable energy, your teacher assigned you to make a tool from the solar panel that can	Student C12 "I will make cleaning tools, decorative lights, toys, fans, robots, and water pumps."	Student E15 "I will make an electric stove, garden lamp, water fountain, and electric bike."

Indicator	Question	Control Group	Experimental Group
	be useful in everyday life. What kind of device will you make? Write down as many answers as you can! For example, make a simple windmill.	Student C20 "I will make street lights, garden lights, sleeping lights, and vehicles with solar panels."	Student E35 "Making fans, computer machines, garden lights, air conditioners, and drones."

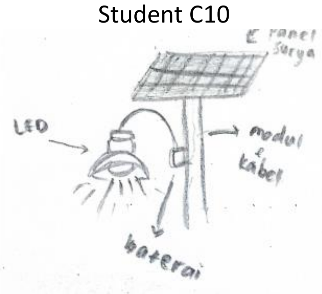
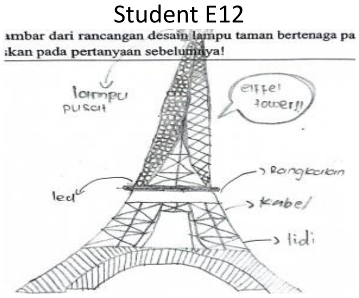
Furthermore, the flexibility sub-dimension measuring students' ability to write ideas from various approaches or modifications obtained the lowest score compared to fluency and originality in both groups. The experimental group students were more able to modify the design based on their knowledge. While the control group wrote answers almost without modification, some students could not answer the question. Examples of the answers of both groups of students are presented in Table 10.

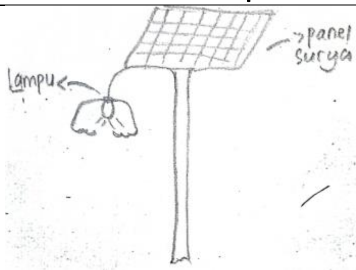
Table 10. Examples of Student Answers in The Flexibility Sub-dimension

Indicator	Question	Control Group	Experimental Group
Real Advance	At a learning media exhibition at UIN Jakarta, you see a demonstration of a toy car powered by solar panels. What scientific questions would you ask? Write down as many as you can.	Student C12 "How do I use the tool?" "Will it work in bad weather?" "How much time does it take to make the tool?"	Student E15 "How do you charge the car when it's dark?" "Can the car be charged with the sun?"
		Student C21 "How do you make the car?" "How does the car move?" "How is the car charged? "How long does it take to assemble the car to make the device?"	Student E29 "Is the use of the car the same as other toy cars?" "How does the solar panel work on the toy car?" "What are the advantages and disadvantages of the solar panel-powered toy car?"

The originality sub-dimension measures students' ability to mention random events that rarely occur in the population (considered pure). Most students in the experimental group were more able to create original designs in their answers. In contrast, the answers in the control group were dominated by pictures of garden lights whose designs were like street lighting. Examples of the answers of both groups of students are presented in Table 11.

Table 11. Examples of Student Answers in The Originality Sub-dimension

Indicator	Question	Control Group	Experimental Group
Science Product	You are a designer assigned a project to design a solar panel-powered garden light. Make a drawing of the draft of the solar panel-powered garden	Student C10  Student C33	Student E12  Student E36

Indicator	Question	Control Group	Experimental Group
	light design you wrote down in the previous question!		

Answer analysis was also carried out on indicators that showed the experimental group's results were lower than the control group. In the Technical Production indicator, students were asked to write down ideas for improvements to a product. Some examples of student answers on the Technical Production indicator:

- Student E23 mentioned three answers, one of which was to make a series of rainproof frame dams.
- Student E33 mentioned four answers, one of which was changing the circuit cable.
- Student C8 mentioned four answers, one of which was adding a time sensor
- Student C20 mentioned nine answers, one of which added batteries, lights, and solar panels.

Meanwhile, on the Science Problem Solving indicator, students were asked to write down energy-related problems found in remote areas and solutions for the problems they found. Some examples of student answers on the Science Problem Solving indicator:

- Student E32 mentioned four answers, one of which is that the problem was the lack of lighting; the solution was to make solar panel-powered street lighting.
- Student E29 mentioned three answers, one of which is that the problem is the lack of educational facilities; the solution is installing solar panels on the school roof.
- Student C4 mentioned three answers, one of which is that the problem found is the difficulty of transportation; the solution is to make solar panel-powered vehicles.
- Student C19 mentioned four answers, one of which is that the problem is limited electricity; the solution is installing solar panels on the house's roof.

This study investigated the impact of design-based STEM on students' scientific creativity on solar energy. The findings show that design-based STEM significantly affects scientific creativity, although the effect size results are still relatively low. This result is consistent with the findings of several previous studies. Zhang et al. (2024) investigated the relationship between design-based STEM learning and scientific creativity between two groups, namely students with design-based STEM and non-STEM learning. The results showed that design-based STEM learning significantly influenced scientific creativity. Another study showed that implementing design-based STEM learning involving 45 prospective secondary school mathematics teachers showed statistically significant differences in scientific creativity ability (Pekbay & Kahraman, 2023). Designing activities in learning can produce various innovative experimental designs (Sari et al., 2020). In STEM activities, the design process helps students construct knowledge about the studied subject, such as renewable energy (Abdurrahman et al., 2023).

Although design-based STEM significantly affects students' scientific creativity, this study shows that scientific creativity scores are still classified as moderate. This result is consistent with the research results by Novitasari (2022), which found that 75% of respondents had scientific creativity that was classified as quite good. Meanwhile, Lailiyah (2018) reported that the average student's creativity was still low. The study results were obtained from a scientific creativity test totalling nine description questions on momentum and impulse. In research by Prajoko et al. (2023), the results of evaluating the creativity of the product in the form of a mind map produced a score of 0.64, which is included in the sufficient category. It is very important to develop student creativity by achieving creativity indicators.

The study also found that, out of seven indicators, five indicators of scientific creativity in the experimental group were higher than the control group. In this study, the Unusual Use and Real Advance indicators had relatively high values in both groups. The results of this study align with research conducted by Astutik et al. (2020). According to him, This is because students can easily comprehend the attributes of the problem. After all, it is related to its use in everyday life. Another finding in this study is only the science product indicator is significantly different between the two groups. In contrast to Fadiawati and Diawati (2023), the study's results differed significantly in terms of the indicator of finding the problem (real advance). This can happen because experiences in everyday life can affect students' creativity. Students in the same field may have very different experiences from each other.

Furthermore, this study also investigated students' scientific creativity scores based on the sub-dimensions of fluency, flexibility, and originality. The findings showed that the average fluency sub-dimension was the highest among the other sub-dimensions. This result is in line with the results of research (Irma et al., 2023). Project tasks in learning direct students to plan, design, and reflect on the findings, which require students to think fluently (Putri et al., 2020). When students are given a problem and asked to produce a product, they are trained to generate many ideas (Isabekov & Sadyrova, 2018; Srikoon et al., 2018). Based on the search results, it was found that the experimental group's flexibility and originality scores were higher than the control group. Similarly, a study on mathematical creative thinking skills found that the experimental group's flexibility and originality scores were higher than the control group (Sufah Iliya Manazila, 2023).

Based on the data analysis, the sub-dimensions of flexibility and originality scores between the experimental and control groups were significantly different. This result follows the research results by (Nanto et al., 2022; Rosid, 2019). Another study conducted by Doğan & Kahraman (2021) showed that the experimental and control groups' fluency, flexibility, and original scores were significantly different in favour of the experimental group that implemented STEM learning. In other words, STEM activities contributed greatly to students' scientific creativity scores.

The application of Design-Based STEM activities in learning is thought to be the reason why the scientific creativity of the experimental group was higher than that of the control group. For example, in the first stage of "Brainstorming", in groups, students identified the problem of the impact of fossil energy use. They decided to make a creative product of automatic garden lights as a solution. The next stage is "Research"; students analyze the characteristics of solar panels as a foundation for designing products. Furthermore, students express their creative ideas by creating the desired lamp design at the "Design" stage. Based on the designs made by students, they can obtain scientific approval (English & King, 2015).

Furthermore, at the "Testing and Constructing" stage, students design automatic garden lights utilizing the knowledge they have gained from the previous stages. To identify and understand the concept of alternative energy, at this stage, students conduct trials on the products they have made (Utami & Nurlaela, 2021). This stage can increase students' interest in learning because it provides an authentic experience in the science learning process (Mills et al., 2020). Based on observations and feedback, students can revise their products by planning modifications to their initial designs (Hacioglu & Dönmez Usta, 2020; Wheeler et al., 2014). Like a scientist, in STEM activities, students use the scientific method to generate creative ideas related to an invention (Doğan & Kahraman, 2021). In the end, students produced a creative alternative energy product in the form of an automatic garden light. It can be said that these processes contribute to students' scientific creativity.

Although it is said to be successful in fostering students' scientific creativity, this research is still limited to only one topic: solar energy. The researcher recommends that future relevant research be conducted on different topics. If the focus of this study is only on scientific creativity, future research is recommended to examine the effect of STEM-based design on improving other skills, such as science literacy (Listiyana et al., 2023), student thinking skills (Siew et al., 2015), or student psychomotor skills (Eroğlu & Bektaş, 2022). In addition, applying design-based STEM learning to Madrasah Aliyah students is one of the challenges in this study. The low value of students' scientific creativity in this study is thought to occur because learning in madrasah prioritizes religious sciences such as fiqh, tafsir, and memorizing the Qur'an (Choeroni et al., 2021). Therefore, further research is needed to explore STEM learning in Madrasahs.

Conclusion

The results of this study identified that STEM education positively affects students' scientific creativity abilities. This study revealed exciting findings that design-based STEM learning significantly influences students' scientific creativity on solar energy. This can be seen from the results of data analysis with an independent t-test of 0.043. At the same time, the effect size test results obtained are in the small category, which is 0.254. This finding underlines the importance of implementing effective learning, one of which is by integrating STEM. Design-based STEM learning allows students to express their creative ideas in making automatic garden light products. This activity can enhance their scientific creativity and understanding of physics concepts, particularly solar energy. Therefore, design-based STEM learning can be an effective strategy for learning. Further research should be conducted by integrating STEM into physics learning.

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