Student Cognitive Analysis in STEAM-Based Pre-Vocational Experiential Learning at the Elementary Level

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Abstract

The Making Indonesia 4.0 program requires an educational system that fosters transdisciplinary, contextual, and practical learning to improve technical literacy and promote environmental sustainability. This study is aimed to assess the effectiveness of STEAM-based pre-vocational experiential learning in improving the cognitive abilities of primary school children. This study employed a quantitative, quasi-experimental One-Group Pretest-Posttest design. The study involved 27 fifth-grade primary school students selected through a purposive sampling technique. The results showed that the average pre-test score for students was 54.70, and most of them fell into the medium range (51–75). After STEAM-based learning was put into place, the average score on the post-test went up to 72.66, and most students moved up to the high group (76–100). According to Hake's criteria (1999), the N-Gain analysis showed an average value of 0.40, which means it was moderate. The Paired Sample t-Test also showed a significance value of $p = 5.75 \times 10^{-7}$ (<0.05), which means that the learning outcomes improved in a statistically significant way. Thus, it can be deduced that STEAM-oriented pre-vocational experiential learning is comparatively beneficial in augmenting students' cognitive abilities. This method positively influences learning outcomes descriptively and is empirically validated, rendering it pertinent for use as a contextual learning technique to enhance 21st-century capabilities in primary education.

Keywords: Experiential learning, Pre-vocational, STEAM, Cognitive assessment, Elementary education.

INTRODUCTION

The 21st century has quickly changed the basic skills that future generations will need. Critical thinking, creativity, teamwork, problem-solving, and technology literacy are essential skills for living in a world that is becoming more digital and innovative (Haryaka, 2025; Ikenga & van der Sijde, 2024). Consequently, the education system must develop these competencies from elementary school to equip students to navigate the complexities of global social and technological advancements (Nikkola et al., 2024).

It is becoming more and more important for Indonesia to develop 21st-century skills because it is entering a demographic dividend phase that will last until 2035. This situation

could lead to economic growth if the workforce is well-prepared, but if it isn't, it could lead to social problems (Firmansyah, 2019). Aligned with the industrial transformation initiative of Making Indonesia 4.0, the education system must promote an interdisciplinary, contextual, and practice-oriented learning methodology to enhance technological literacy and environmental sustainability (Darmawati & Pulunga, 2025). The STEAM approach is regarded as a relevant strategy in this initiative (Keum & Baek, 2025).

Research on the application of STEAM in primary education indicates positive results in improving higher-order thinking skills and student engagement (Susiloningsih et al., 2025). STEAM-based education provides more substantial, contextual learning experiences and fosters interdisciplinary understanding (Muntazah et al., 2025). Another study found that STEAM education boosts students' motivation and their ability to connect what they learn in class to things that happen in the real world (Cook et al., 2025). The Project-Based STEAM methodology in Indonesia has demonstrated an enhancement in students' engagement and numerical proficiency (Ranak et al., 2023). These results highlight the importance of STEAM as a potential educational approach.

The integration of STEAM is augmented when linked to project-based and pre-vocational education. Project-based learning facilitates experiential learning by connecting theoretical concepts to practical applications through investigation, creation, and assessment of outcomes (Adah Miller et al., 2025). In this context, pre-vocational education fosters essential technical skills, problem-solving abilities, and occupational awareness, thereby improving students' long-term readiness to adapt to socio-technological changes (Lind et al., 2024). Pre-vocational education does not direct students toward particular careers; rather, it lays the groundwork for essential skills in labor and technology (Rahmawati et al., 2025).

The implementation of the Mini Solar Panel House project aligns with Kolb's Experiential Learning Theory, which emphasizes a cycle of concrete experience, reflection, abstract conceptualization, and active experimentation (Kolb & Kolb, 2021). Students learn about energy conversion, electrical circuits, and sustainability by building, designing, and testing a model of a solar-powered home. This education fosters renewable energy literacy, creativity, collaboration, and environmental awareness, which are essential components of future-oriented learning (Entang et al., 2024; Sutoyo & Yudhanto, 2023).

Despite the positive results of research on STEAM and project-based learning, there are still not many studies that systematically use STEAM in pre-vocational settings, especially in primary education with renewable energy. There is limited documentation on tangible practical representations that demonstrate students' understanding of renewable energy

concepts through experiential learning in integrated projects (Rusmana et al., 2025). This circumstance establishes a research void that requires addressing.

This study examines the impact of experiential pre-vocational learning through the STEAM approach on the cognitive development of elementary school students, particularly in understanding the basic principles of renewable energy and the functioning of solar panels. Although the STEAM method is commonly employed to improve conceptual understanding through project-based learning, empirical studies specifically investigating its effects on cognitive development in pre-vocational contexts at the primary school level are limited (Marina & Michalis, 2025). This situation raises questions about how much the Mini Solar Panel House project could help students learn how to use scientific knowledge, solve problems, and put what they learn into practice.

This study sought to assess the degree of students' cognitive development within the context of STEAM-focused pre-vocational education in elementary schools. The research findings are expected to provide theoretical insights into the integration of STEAM and pre-vocational education, as well as practical contributions in developing learning designs that promote technical literacy and comprehension of sustainable energy from a young age.

METHOD

The application of the STEAM methodology in primary pre-vocational education is expected to improve students' conceptual understanding while fostering positive attitudes and practical skills relevant to real-world contexts (Salazar et al., 2025). To evaluate the effectiveness of the STEAM initiative using the pre-vocational experiential learning strategy: the Mini Solar Panel House, it is necessary to have a pedagogical framework that measures changes in students' overall knowledge.
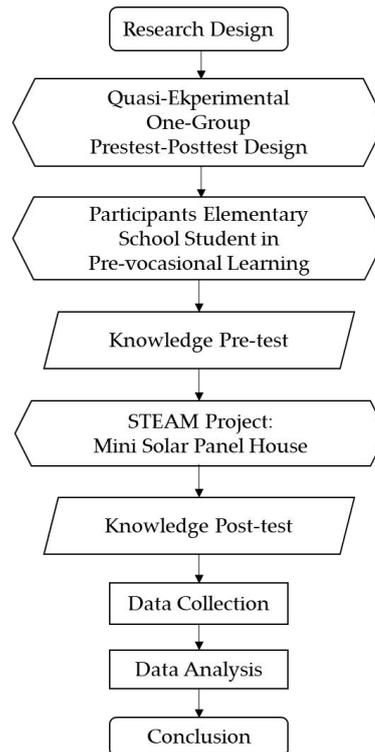
Figure 1. Flowchart of the research methodology

Figure 1 depicts a flowchart of the study methodology utilizing a quantitative framework via a quasi-experimental One-Group Pretest–Posttest Design. This methodology was employed because the study's context did not allow for the formation of a control group or the random assignment of participants; nevertheless, researchers were able to evaluate changes in learning outcomes following the intervention (Capili & Anastasi, 2025). This design uses a measuring framework that goes from O_1 to X to O_2. O_1 is a pre-test that checks what students already know, X is a STEAM-based learning intervention through the Mini Solar Panel House project, and O_2 is a post-test given after the intervention. By comparing the values of O_1 and O_2, researchers can see how much students' understanding of concepts changed because of the learning intervention. This makes it possible to test the success of using the STEAM method in pre-vocational education in a real-world way.

The study included 27 fifth-grade primary students participating in pre-vocational learning activities. Participants were selected via purposive sampling based on their involvement in renewable energy initiatives and alignment with pre-vocational skill development objectives. The Mini Solar Panel House project made learning easier by using themes from science, technology, engineering, arts, and mathematics (STEAM) to build a small model of a house powered by solar panels.

The research procedure consisted of three primary phases: preparation, implementation, and evaluation. During the preparatory phase, researchers developed instructional materials,

project worksheets, and validated assessment tools. The implementation phase included project-based learning with the Mini Solar Panel House, which is a STEAM (science, technology, engineering, arts, and mathematics) project. Students worked together to come up with ideas, build, and test the solar panel home prototype while their teachers watched.

A multiple-choice exam was used to test students' understanding of the principles of solar energy and renewable energy technologies. Learning outcome data were gathered through a pre-test (0_1) before the intervention and a post-test (0_2) following the STEAM-based learning intervention associated with the Mini Solar Panel House project. Descriptive statistics were used to look at the data and find patterns in how well students did.

An inferential analysis employing a paired sample t-test was conducted to evaluate the significance of improvements in students' cognitive abilities subsequent to their involvement in the learning intervention. The threshold for significance was set at $\alpha = 0.05$. The test results provide a basis for assessing whether a significant difference exists between the pre-test and post-test results (Firdaus et al., 2025). Prior to conducting the inferential analysis, a Shapiro-Wilk test was performed to verify the normal distribution of the data, ensuring that the assumptions for the paired sample t-test were strictly met. An N-Gain score was also calculated to evaluate the effectiveness of improving students' understanding after the educational intervention. The results of this study establish a standard for assessing the effectiveness of STEAM-focused pre-vocational education in improving the cognitive abilities of primary school children, particularly in relation to their understanding of renewable energy concepts and their practical applications in everyday life.

RESULTS AND DISCUSSION

Preliminary Assessment Outcomes

The results of the pre-test showed that students had different levels of understanding of STEAM-related pre-vocational content before the class. The scores of the students ranged from 15 to 90, with most of them falling between 51 and 75 (see Figure 2). This means that most students have a good basic understanding of the material that will be tested and are ready to learn more.

Most of the students in the class are in the "adequate" range, which means their scores are between 51 and 75. This group has the ability to learn and can improve their understanding through structured educational activities. There are also students in the lower range (26–50) who need help with basic ideas to help them understand better while they are learning. Some kids also fall into the very low range (0–25). This group has a lot of trouble

understanding things, so they need more help using adaptive, collaborative learning methods that are meant to help them understand basic ideas better
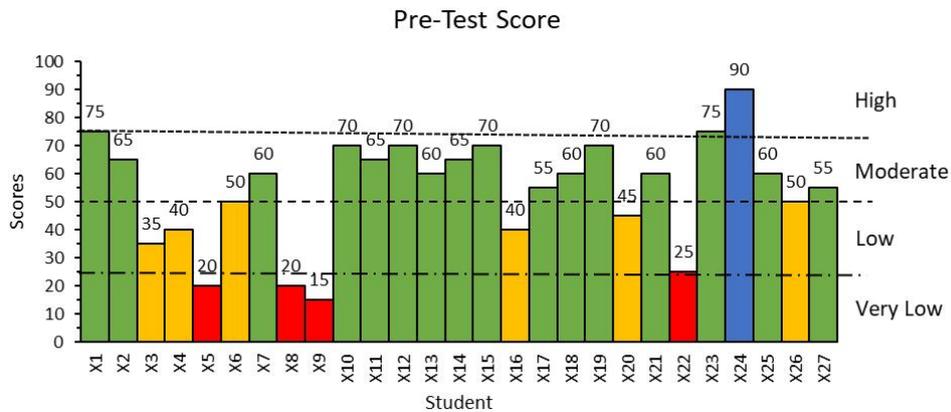

Figure 2. Pre-Test Score

The pre-test results show that students are not all ready to learn, but most of them have enough resources to do so. These results provide a basis for educators to implement a differentiated learning strategy, facilitating optimal development for all children.

Post-Assessment Outcomes

Post-assessment results showed that students' skills improved after they took part in STEAM-focused pre-vocational education. The scores of the students ranged from 25 to 100, but most of them were between 76 and 100 (see Figure 3). This means that most students learned the material very well and understood it better than they did before. This improvement shows that teaching methods that focus on STEAM can help students improve their critical thinking and problem-solving skills.
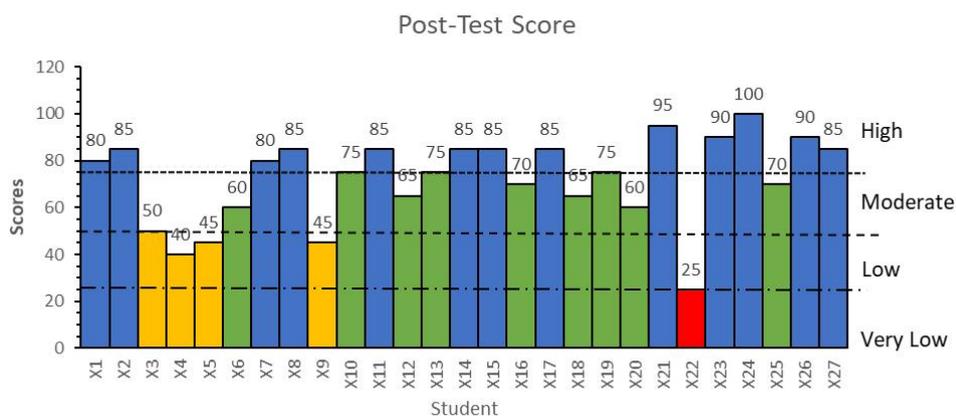

Figure 3. Post-Test Score

The score classification showed that the high group (76–100) was the largest group, followed by the medium group (51–75). The advanced group of students showed a lot of improvement from the pre-test results, which means that the teaching method used was

successful in getting students to participate and understand the concepts better. At the same time, the medium group showed good progress, but they need more help using ideas and thinking about what they learned to get a better grade.

On the other hand, only a small number of students stayed in the low (26–50) and very low (0–25) groups. Students in these groups need strict guidance and personalized learning methods to improve their basic understanding. The post-test results showed that using STEAM-based learning greatly improved educational outcomes and created a lively, collaborative learning environment that aimed to improve students' overall skills.

Analysis of Pre-Test and Post-Test Outcomes

A comparison of the number of students in each score range category before and after the test. After the adoption of a STEAM-based curriculum, students moved to higher scoring categories overall. The majority of students (16) were in the medium group (51–75) on the pre-test, and only one student was in the high group (76–100). This means that the students' initial skills were different, and most of them had a moderate level of understanding.

The post-test results showed a big jump in the high category (76–100) to 13 students during the learning process. This means that most of the students improved their learning outcomes and reached a higher level of mastery. On the other hand, the number of students in the very low (0–25) and low (26–50) groups fell from 4 and 6, respectively, to just 1 and 4, respectively. This decrease shows that the learning method that was used helped students who had trouble understanding things before.
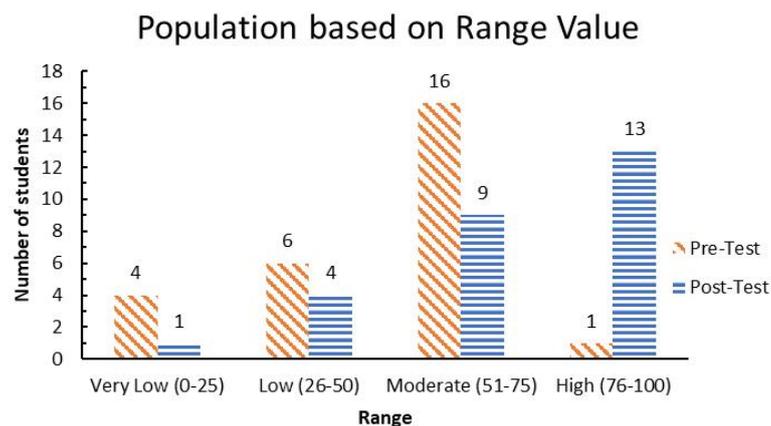

Figure 4. Population based on Range Value

Based on Figure 4, the change in score distribution supports the idea that STEAM-oriented pre-vocational education greatly improves students' cognitive and conceptual skills. The significant shift from the moderate to high category indicates a consistent improvement in understanding across nearly all student demographics. Consequently, these findings substantiate that the STEAM-based learning methodology improves learning outcomes

quantitatively and positively impacts the quality of knowledge within the classroom (Montero-Izquierdo et al., 2024).

Enhancement Derived from Project Groups

Students were split into five groups for the Mini Solar Panel House project. Each group had two girls and three to four boys. This made it easier to see how group segmentation affected the improvement of knowledge.
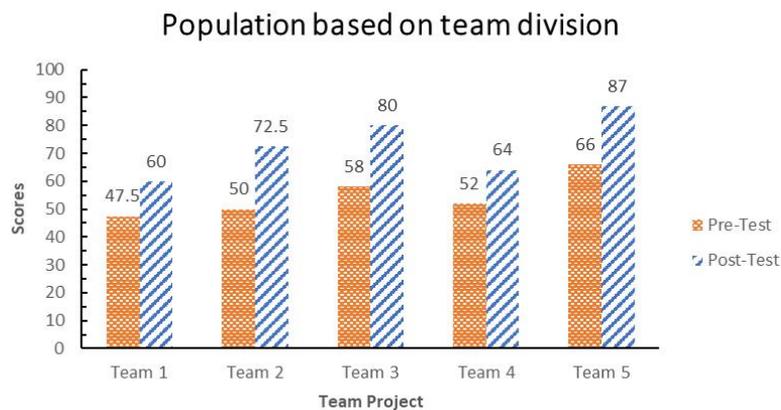

Figure 5. Population based on team division

Figure 5 showing the average scores on the pre-test and post-test for each project team shows that all teams showed an improvement in learning outcomes after STEAM-based learning was introduced. The average scores for teams during the pre-test phase ranged from 47.5 to 66, which shows that they all had different but reasonable starting skills. After the learning period, all teams showed big improvements in their scores: Team 1 went from 47.5 to 60 (26.3% increase), Team 2 went from 50 to 72.5 (45% increase), Team 3 went from 58 to 80 (37.9% increase), Team 4 went from 52 to 64 (23.1% increase), and Team 5 went from 66 to 87 (31.8% increase).

Analysis of N-Gain

The chart showing students' N-Gain scores shows how much better their learning outcomes got after they took part in STEAM-based pre-vocational education. The N-Gain score assesses learning effectiveness by examining the difference between pre-test and post-test outcomes. The graph shows that the largest group of students, 14, or about 52%, is in the middle range (15–30). The next group is the low group (5–10), which has 7 students, or about 26%.

The next group is the high group (35–65), which has 3 students, or about 11%. The next group is the zero group (0), which has 2 students, or about 7%. The last group is the negative group (-5), which has 1 student, or about 4%.
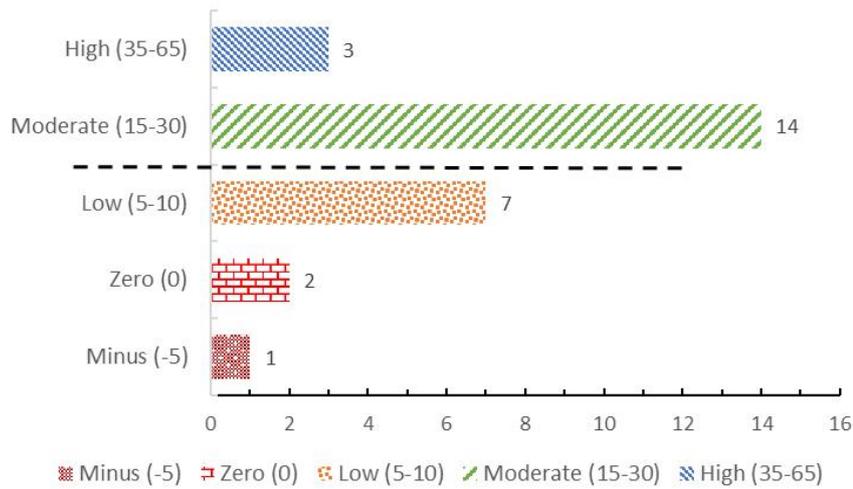
Figure 6. Analysis of N-Gain

Figure 6, in the group comparison, there were 17 students (about 63%) in the medium and high categories, while there were 10 students (about 37%) in the low, zero, and minus groups. This percentage means that most students saw big improvements in their learning after taking part in STEAM-based education. The medium group was the biggest, which means that most students improved their skills on a regular basis. The fact that there were students in the high group shows that some people made great progress..
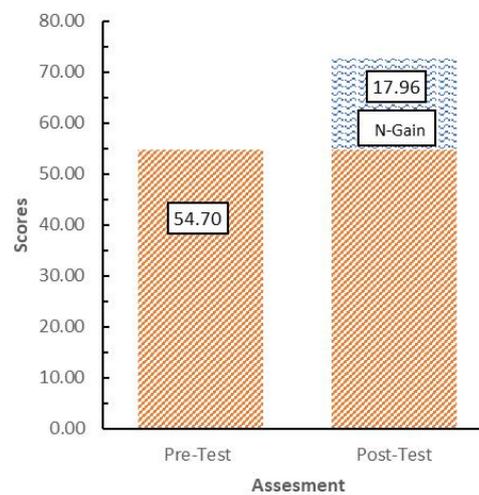

Figure 7. Comparation test score

Figure 7 revealed that the average pre-test score of students was 54.70, whereas the average post-test score rose to 72.66. The rise of 17.96 points shows that students' skills improved after they took part in STEAM-based pre-vocational learning. Overall, these results show that applied learning had a big impact on how well students learned. To measure the

level of learning effectiveness, the N-Gain calculation was carried out using the Hake & Reece, (1999) formula:

$$g = \frac{(Post - Pre)}{(100 - Pre)}$$

$$g = \frac{(72.66 - 54.70)}{(100 - 54.70)} = \frac{17.96}{45.30} \approx 0.40$$

The average N-Gain score was 0.40, which means it was moderate ($0.3 \leq g < 0.7$). Hake's criteria indicate that STEAM-oriented pre-vocational education is relatively effective in improving student competencies. This achievement indicates that most students exhibited improved conceptual understanding and critical thinking skills subsequent to their participation in the learning process.

The significant increase in post-test scores shows that the STEAM-based learning method creates a more contextual, integrated, and challenging learning environment for students. Combining science, technology, engineering, art, and math in school helps students connect what they learn in theory to what they do in real life. This supports the idea that STEAM-based education focuses on more than just learning facts; it also focuses on developing skills like problem-solving, working together, and being creative. The test results support previous research that STEAM-based pre-vocational education improves children's cognitive skills. The average score on the pre-test was 54.70, and the average score on the post-test was 72.66. This means that the average N-Gain was 0.40 (moderate category) according to Hake's (1999) criteria. This shows that the teaching method used is moderately effective in improving student learning outcomes. The data indicate that the learning intervention yields both a positive descriptive effect and statistical significance, thereby suggesting that the implementation of STEAM learning substantially improves student learning outcomes.

This effectiveness may be clarified by the characteristics of STEAM-focused pre-vocational education, which emphasizes the integration of science, technology, engineering, art, and mathematics through collaborative and project-based activities (Ammar et al., 2024). This approach encourages students to think critically and creatively, making it easier for them to see how what they learn in school can be used in real life (Wang et al., 2024). The results from the t-test and N-Gain analysis provide empirical evidence that STEAM-based pre-vocational education has significantly and measurably improved student learning outcomes.

Theoretical Synthesis: Why STEAM Is Effective

The efficacy of STEAM-oriented pre-vocational education can be elucidated through a synthesis of established pedagogical theories that prioritize significant learning, interdisciplinary integration, and the cultivation of twenty-first-century competencies. The substantial enhancement in students' learning outcomes, as demonstrated by descriptive statistics and N-Gain analysis, signifies that STEAM operates not only as an innovative instructional strategy but also as a theoretically grounded pedagogical framework congruent with the manner in which students construct and apply knowledge in authentic contexts (Mansour et al., 2026).

1) Constructivist Perspective: Learning as Active Knowledge Construction

From a constructivist standpoint, STEAM-oriented pre-vocational education is efficacious as it regards students as proactive creators of knowledge instead of mere passive recipients of information (Shih, 2025). Students directly deal with real-world problems that need the use of scientific, mathematical, and technological ideas through hands-on, project-based activities. This experiential learning process helps students connect abstract theory with real-world use. This leads to a better understanding of concepts and better memory retention, as shown by the big change from medium to high achievement categories after the intervention (Zamiri, 2024).

2) Interdisciplinary Integration and Cognitive Theory

STEAM is effective because it is made up of different fields, which is in line with cognitive learning theory because it helps people build integrated and coherent mental schemas. Integrating science, technology, engineering, art, and mathematics into a cohesive problem-solving framework diminishes cognitive fragmentation and enhances information processing efficiency (Barkah et al., 2024; Asrizal, 2023; Haka et al., 2025). The rise in post-test scores and the moderate N-Gain value suggest that this integrative approach improves students' cognitive abilities and encourages a more profound and transferable understanding across various domains (Yao & Lin, 2025).

3) Project-Based Learning and Contextual Instruction

Project-based learning is a way to use STEAM that creates a learning environment that connects what you learn in school with how you use it in the real world. When students work on real projects like the Mini Solar Panel House, learning becomes more relevant and important, especially in a pre-vocational setting. The steady progress of all project groups shows that teaching that is based on the context and the project helps students learn both

concepts and practical skills that are important for getting ready for work (Guaya et al., 2025; Rehman et al., 2024).

4) Social Constructivism and Collaborative Learning

From a social constructivist point of view, STEAM-based learning works because it puts a lot of emphasis on working together and interacting with others as important ways to build knowledge. Group-based projects promote peer learning, discussion, and collaborative problem-solving, enabling students with greater initial competencies to assist those with lesser starting abilities (Chen & Dong, 2024). The decrease in low- and very low-achieving students following the intervention demonstrates that collaborative learning within the STEAM framework fosters inclusive education and equitable academic results (Ventista & Brown, 2023).

5) Development of Twenty-First-Century Skills

STEAM-based instruction effectively cultivates twenty-first-century skills, such as critical thinking, creativity, collaboration, and problem-solving, which are vital for pre-vocational education. The arts component promotes creative design and adaptable thinking, enhancing analytical reasoning in science and mathematics (Veziroglu-Celik et al., 2025). The substantial enhancement in post-test performance indicates that students acquired the capability to apply knowledge flexibly in unfamiliar contexts, thereby underscoring STEAM's significance in equipping learners for intricate and evolving professional landscapes (Deák & Kumar, 2024; Zhi et al., 2025).

CONCLUSION

An analysis of pre-test and post-test data from STEAM-based pre-vocational instruction reveals a significant improvement in students' cognitive abilities. The pre-test results showed that most students were in the intermediate group (51–75), with an average score of 54.70. This meant that they had a good start to understanding, but it wasn't evenly spread out. After STEAM-based learning was put into place, the average score on the post-test went up to 72.66, and most students moved up to the high group (76–100). The change in the distribution of scores shows that STEAM-based instruction helps students understand concepts better and get ready to learn.

The N-Gain study revealed an average score of 0.40, categorizing it as moderate using Hake & Reece, (1999) standards. This indicates that STEAM-focused pre-vocational education is quite effective in improving student learning outcomes. About 63% of students made moderate to significant progress, while a small number showed only minor progress. The results show that a teaching method that regularly includes science, technology,

engineering, art, and math improves students' ability to think critically, work together, and be creative.

The results of the Paired Sample t-test confirmed these findings, producing a significance value of $p = 5.75 \times 10^{-7}$, which is lower than $\alpha = 0.05$. Before conducting the paired-sample *t*-test, the assumptions of normality and variance homogeneity were evaluated using the Shapiro–Wilk test and the F-test, respectively. The Shapiro–Wilk results indicated that both the pretest ($p = 0.110$) and posttest ($p = 0.072$) data were normally distributed ($p > 0.05$). Thus, the normality assumption was satisfied. Furthermore, the homogeneity test yielded an F value of 1.14, suggesting that the variances between the pretest and posttest scores were comparable. Accordingly, the assumption of homogeneity was met, and the data were deemed suitable for subsequent parametric analysis using a paired-sample *t*-test. This shows that the results of the pre-test and post-test were very different, which means that the improvement was not due to chance but to the effectiveness of the STEAM-based pre-vocational learning implementation. Thus, it can be concluded that this learning not only has a positive descriptive effect, but it is also statistically significant in improving students' cognitive abilities. STEAM-based education has been shown to greatly improve the quality of student learning processes and outcomes. It also helps students develop 21st-century skills like critical thinking, communication, teamwork, and creativity (Spyropoulou & Kameas, 2024).

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Availability of data and material

The datasets generated and/or analyzed during the current study are available from the first author upon reasonable request.

Ethics approval

The study was approved by Instituonal Review Boards (IRB) of the Universitas Sultan Ageng Tirtayasa, Indonesia on 25 March 2026

Patient consent statement

Informed consent was obtained from all individual participants included in the study.

Permission to reproduce material from other sources

No material from other sources was used in this manuscript.

Clinical trial registration

This study is not a clinical trial and does not require registration.

Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author used QuillBot in order to improve the language and readability. After using this tool, the author reviewed and edited the content as needed and takes full responsibility for the content of the publication.

Credit authorship contribution statement

Rusdi Febriyanto, Ade Dwi Putra Janata, Ananda Yhuto Wibisono Putra, Ricky Cahyasari Putra, Ikhsanudin Ikhsanudin, R. Ahmad Zaky El Islami, Nguyen Van Bien, Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Project administration, Methodology, Investigation, Funding acquisition, Formal analysis, Data curation, Conceptualization. Ahmet Selçuk Akdemir: Writing – review & editing, Formal analysis, Data curation.

Declaration of competing interest

The authors declare that they have no competing financial or non-financial interests in relation to this study.

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