Al-Ishlah: Jurnal Pendidikan
Vol.17, 4 (December, 2025), pp. 7957-7966
ISSN: 2087-9490 EISSN: 2597-940X, DOI: 10.35445/alishlah.v17i4.8629

Implementation of Deep Learning-Based STEAM on Students' Critical Thinking, Communication, Collaboration, and Creativity Skills

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ARTICLE INFO

Keywords:

collaboration;
communication;
critical thinking;
deep learning;
STEAM

Article history:

Received 2025-09-17
Revised 2025-11-01
Accepted 2025-12-31

ABSTRACT

The objective of this research is to implement STEAM learning grounded in Deep Learning to enhance students' Critical Thinking, Communication, Collaboration, and Creativity (4C) abilities. The study was carried out at SDN Masalima IV utilizing a mixed methods approach that integrates both qualitative and quantitative analyses. The qualitative data were gathered through observation, interviews, and documentation, whereas the quantitative data were acquired through pretest and post-test. The total number of research subjects was 21 students. The analysis of qualitative data revealed that every phase of STEAM learning (Observe, New Idea, Innovation, Creativity, Society) was fully executed and successfully enhanced students' 4C skills, which include critical thinking, communication, collaboration, and creativity, through contextual projects that combined science, technology, art, and local culture. The quantitative data analysis results indicated that the average score on the pre-test was 47.19, whereas the average score on the post-test rose significantly to over 81.67. The normality tests using Kolmogorov-Smirnov and Shapiro-Wilk confirmed that the data followed a normal distribution. Additionally, the paired sample t-test yielded a significance value of 0.000 (<0.05), demonstrating a significant difference in learning outcomes before and after the treatment and therefore, it can be said that using STEAM-based Deep Learning is not only effective for enhancing academic performance, but also significantly contributes to developing essential skills for the 21st century, making it a valuable alternative model for innovative learning in schools.

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1. INTRODUCTION

In today's globalized world and during the ongoing industrial revolution 4.0, moving towards society 5.0, education is essential for creating skilled, flexible, and highly competitive human resources (Aini & Ridwan, 2021; Aini & Yasid, 2022; Tahar et al., 2022). It is no longer adequate for education to focus solely on theoretical knowledge; it must also cultivate a generation of creative, critical thinkers

who are capable of innovation and possess strong social and emotional skills (Abdillah, 2020; Ar et al., 2024). The rapid advancements in technology have transformed our lifestyles, work environments, and learning processes (Aini, 2021). Consequently, the education system must adapt to these changes by offering a learning approach that is relevant, flexible, and contextual. The curriculum represents one aspect of educational transformation, allowing both educators and students the freedom to develop according to their needs and potential (Hasanah & Haryadi, 2022). A method that aligns with this vision is STEAM (Science, Technology, Engineering, Arts, and Mathematics) based learning, which promotes interdisciplinary learning, enhances problem-solving abilities, and nurtures creativity and innovation (Aini, Misbahudholam AR, et al., 2024; Aini et al., 2025; Yuniar et al., 2020). The stages of STEAM learning include observation, idea generation, innovation, creativity, and societal impact (Sari et al., 2021). By integrating STEAM into the curriculum, students gain not only academic knowledge but also essential 21st-century life skills that are increasingly demanded in the workforce and global society. Today, STEAM learning has gained immense popularity due to its effectiveness in helping students grasp concepts and creatively tackle problems. (Aini et al., 2025).

In today's world, characterized by technological progress and digitalization, mastering mathematics has become an essential skill for everyone (Aini et al., 2020; Aini, 2021b; Saputra, 2024). Mathematics is not merely about calculations; it significantly contributes to developing logical, critical, and systematic thinking necessary for contemporary life. Because mathematics can be abstract, which often makes it difficult for students to grasp concepts, a more realistic learning approach is required. One effective method is Deep Learning, which emphasizes a thorough understanding of concepts and ongoing mastery of skills. With Deep Learning, students are encouraged to go beyond merely memorizing formulas or procedures; they learn to relate mathematical theories to real-life situations, making their knowledge more relevant and applicable (Raup et al., 2022). Deep Learning is a concept introduced by Abdul Mu'ti, the Minister of Elementary and Secondary Education (Mendikdasmen), aimed at transforming the learning paradigm to focus on deep understanding. This method motivates students to move past simple memorization and to internalize knowledge in a more meaningful and lasting manner (Putri, 2024).

Deep Learning aids students in fully understanding the material and encourages them to build a more complex and connected comprehension, allowing them to use their knowledge in various situations and contexts (Wijaya et al., 2025). Based on thorough analysis, deep learning comprises three key concepts: meaningful learning, mindful learning, and joyful learning (Diputera et al., 2024). These concepts align with the needs of learners in today's global era and are consistent with current curriculum advancements. The curriculum, as a form of educational policy innovation, offers greater flexibility for students and teachers to shape the quality of learning (Asmoni et al., 2022). Through this curriculum, students are supported in learning in a flexible, contextual, and meaningful manner. The primary emphasis is on enhancing 21st-century skills, known as Critical Thinking, Communication, Collaboration, and Creativity (4Cs) (Lestari & Hindun, 2023). These four competencies are essential foundations for navigating a world characterized by complexity and rapid change. Critical Thinking focuses on the ability to think logically, analyse, and systematically solve problems. Communication involves the skills of expressing ideas clearly and effectively, as well as active listening. Collaboration pertains to the ability to work together, share responsibilities, and appreciate differing opinions. On the other hand, Creativity highlights the capacity to generate new ideas, innovate, and think outside the box (Aziz et al., 2024). Therefore, the 4Cs skills are not only supplementary but are central to education that aligns with the trajectory of modern world development.

To align with curriculum development, there is a need for learning innovations that can equip graduates with the skills to actively participate in various life aspects. However, initial observations by researchers on Masalembu Island, the outermost island of Sumenep District, which is situated between Madura and Kalimantan, reveal some issues. There is one elementary school, SDN Masalima IV, located in Masalima Village, Masalembu District, where the 4Cs skills are still lacking in the learning process. This is due to students being less engaged and often bored during lessons. As a school on

Masalembu Island, SDN Masalima IV faces challenges such as limited access, resources, and learning innovations. This situation highlights the need for research and development of learning models that can enhance students' 4Cs skills. Therefore, this research aims to contribute significantly by providing innovative learning that aligns with curriculum advancements and meets students' needs.

2. METHODS

The subject of this study was the students from SDN Masalima IV, situated in Masalima Village, Masalembu District, for the Academic Year 2025/2026. These students have embraced the independent curriculum and were chosen randomly by the researchers. The site for this research was chosen for several reasons: 1) Masalembu Island is the most remote island in Sumenep Regency, situated geographically between the islands of Madura and Kalimantan, 2) the use of traditional learning methods has led to boredom and a lack of motivation, 3) Deep Learning-based STEAM education has not yet been implemented, 4) the students exhibit low proficiency in 4Cs skills, and 5) this school serves as a representation of the educational circumstances in the remote islands in Sumenep Regency, which faces challenges such as limited access and learning resources. A mixed method approach is applied in this study, which means integrating both quantitative and qualitative techniques to enhance the comprehensiveness, validity, reliability, and objectivity of the data collected. The research was carried out through a Sequential Exploratory design, beginning with qualitative method followed by quantitative method (Gustini, 2022). The qualitative phase focused on implementing Deep Learning-based STEAM education, while the quantitative phase assessed 4Cs competencies through pre-test and post-test evaluations. The assessment of 4Cs skills in this study was based on the indicators outlined in the table provided by Fachmi (Fachmi et al., 2022).

Table 1. 4Cs Ability Indicators

4Cs Ability	Indicators
Critical Thinking	a. the ability to apply inductive and deductive reasoning for comprehending and resolving issues; b. the ability to analyse the interrelationships between parts of a system to produce a comprehensive understanding of complex problems; c. the ability to analyse and evaluate facts objectively; d. the ability to draw logical conclusions based on the results of analysis; e. the ability to solve problems, both conventionally and through innovative approaches.
Communication	a. expressing thoughts and ideas both verbally and in writing; b. using communication skills for various purposes, such as conveying information, persuading, and collaborating; c. being able to utilize various media and technologies to support the communication process during learning.
Collaboration	a. demonstrating the ability to work effectively in groups; b. accepting the sharing of responsibility and contribute to the completion of group tasks; c. showing mutual respect by providing constructive feedback to fellow friends
Creativity	a. creating new ideas; b. expanding the basic idea to enhance and maximize creative efforts; c. applying the creative idea as a tangible contribution to daily life.

The following are the learning steps that will be used in this study.

Table 2. Learning Steps

STEAM Learning Stages Based on Deep Learning	4Cs Skills in the Learning Process
Observation step (Observe) Mindful Learning	Students are encouraged to make detailed observations of learning objects or phenomena with complete awareness. This process occurs not only individually, but also through group activities that focus on teamwork. Students are split into small groups to observe phenomena, document their observations, and share their viewpoints. This approach not only fosters mindfulness in noticing details but also enhances collaboration skills, allowing students to value others' contributions, adjust to working in teams, and create a shared understanding.
New idea step (New Idea) Meaningful Learning	Students are encouraged to link their prior knowledge with new concepts or experiences they are learning. Instructors present stimuli such as contextual problems, real-life phenomena, or case studies that motivate students to think and discover new ideas. The new ideas that arise are not merely memorized facts, but rather the outcome of creating meaning from experiences and prior knowledge.
Innovation Step (Innovation) Joyful Learning	Learning aims to create enjoyable and challenging experiences that inspire learners to come up with new ideas. Instead of only tackling routine problems, learners are encouraged to think critically (Critical Thinking) and explore different solutions to problems.
Creation Step (Creativity)	Students are guided to process the knowledge and learning experiences they have acquired into a new work or product that reflects their understanding (creativity). This process emphasizes not only the final result, but also how students develop ideas, try various strategies, and dare to express their ideas in an original way. Teachers provide students with the freedom to express their ideas in the form of projects, models, presentations, or other innovative works in accordance with the context of the material.
Value Step (Society)	Learners are invited to reflect, express, and communicate the understanding and learning experiences they have gained. This process not only emphasizes academic achievement, but also the ability of students to convey their ideas, ideas, and work clearly, coherently, and can be understood by others (Communication).

The data collection involved observations, interviews, and tests. The purpose of the observations and interviews was to gain a clear understanding of how STEAM learning based on Deep Learning was implemented, particularly in mathematics learning. The tests, including pre-tests and post-tests, were conducted to more objectively assess the growth of students' 4Cs skills. The research instruments used were observation sheets, interview guidelines, and tests focused on 4Cs skills in mathematics learning. Qualitative data gathered from observations and interviews were and were analyzed through data reduction, data presentation, validation via triangulation, and drawing conclusions. The quantitative data from the test results were analyzed using quantitative methods to evaluate the enhancement of the students' 4Cs skills.

3. FINDINGS AND DISCUSSION

The results of this study focused on how learning is applied. STEAM-based Deep Learning was designed to improve Critical Thinking, Communication, Collaboration, and Creativity (4Cs) skills in grade IV students at SDN Masalembu. This research employed a mixed-method approach, resulting in both qualitative analysis of the learning process and quantitative analysis concerning the enhancement of 4Cs skills. The qualitative aspect was carried out through interviews and observations to gain a detailed understanding of the implementation of STEAM learning based on Deep Learning. In contrast, the quantitative aspect involved tests designed to assess the improvement in students' Critical Thinking,

Communication, Collaboration, and Creativity (4Cs) skills. This methodology facilitates the integration of qualitative and quantitative data, leading to more comprehensive results.

The findings indicate that the learning process can be outlined in several stages as detailed below. First Step. During the observation phase (Observe), the learning process was conducted using a Mindful Learning approach, which highlighted the complete engagement of the learners in reinterpreting the concepts they had previously acquired. In this context, Mindful Learning stressed the importance of the learners being fully aware during the learning experience. It went beyond mere repetition of material; instead, learners were encouraged to engage in comprehensive learning activities, focused on the intricacies of the concepts being studied, and actively investigated the knowledge at hand with heightened awareness. The learners were divided into heterogeneous small groups based on differentiation of learning readiness. This grouping aimed to allow each learner to complement each other, thus creating a conducive and balanced learning dynamic. In their groups, the learners re-explore the material previously learned. They explored their knowledge through various ways, such as reading sources, searching for information on the internet, and reviewing memories and previous learning notes. Learning awareness is seen when learners actively sought additional information from reading sources, browsed the internet, and utilized their notes. From the Science side, the learners observed objects in their daily lives and identified the shapes of flat shapes from these objects (square, rectangle, triangle, kite), so that the learners realized that flat shapes were found in everyday life.

This showed mindfulness in the learning process, which was full engagement to gain a more comprehensive understanding. The teacher acted as a facilitator who guided the discussion, provided direction, and ensured that each group member actively participated. The observation results showed that at this stage the Collaboration indicator began to appear clearly. Learners showed the ability to work together in groups, where they shared information, exchanged opinions, and provided input to the ideas presented. In addition, learners also seemed to respect the opinions of their groupmates by listening actively and accepting the division of responsibilities in completing the task. The collaboration built in the Observe stage with Mindful Learning not only helped the learners re-understood the material, but also fostered mutual respect, cooperation, and made a real contribution to the success of the group. Therefore, this observation step contributes significantly to fostering 21st century skills, especially the Collaboration aspect, as part of strengthening Deep Learning-based STEAM learning.

Second Step. During the New Idea stage, students were encouraged to generate innovative concepts grounded in previously gathered information. The application of Meaningful Learning was apparent in this phase, as learners engaged actively by connecting their prior knowledge with the new information they acquire. This made the learning process more meaningful and oriented towards deep understanding. The learners first observed phenomena and sought additional information from various sources, including textbooks, articles, and digital media (Technology). The information obtained was then discussed in groups to find its relevance to the learning topic. This process required full involvement of the students in sorting, selecting, and interpreting information to fit the context of the problem being discussed. The results showed that at this stage the learners began to practice linking old concepts with new knowledge. For example, the learners look for ideas from textbooks and the internet, then concluded that each flat shape had the characteristics of calculating area and perimeter. Furthermore, the learners found a new idea that the area of a triangle could be derived from a rectangle, and understood the relationship between flat shapes. At this stage, the learners were encouraged to come up with new ideas based on the results of analyzing the information they had obtained. These ideas emerged through group discussions where each member contributed their thoughts. This shows that the learning process does not stop at conceptual understanding alone, but continues to the creation of new, original ideas.

Third Step. During the innovation phase, the students received guidance to transform the ideas generated in the earlier stage into concrete forms, including solutions, basic products, or models suitable for a learning environment. In this research, students created drawings with cardboard (Engineering). The application of Joyful Learning was apparent in this phase, as the activities were

crafted to promote a joyful and stimulating learning environment, encouraging students to feel excited about their creativity. Students were actively involved in the process of trying out and developing the ideas they had formulated. The activities included group discussions, straightforward experiments, and designing solutions. The learning environment became more vibrant as the teacher allowed students to express their creativity and supported the group's needs based on the ideas they generated. Joy, enthusiasm, and satisfaction were evident when students were able to express their ideas in the form of tangible works. This stage also reflected the Critical Thinking indicator. The students used inductive and deductive reasoning to assess the strengths and weaknesses of the ideas they developed. They also analysed the interrelationships between parts of the idea to produce comprehensive outputs and evaluate the facts obtained during the exploration process. This critical thinking process was evident when the students tested whether their ideas were relevant, logical, and applicable in solving real problems.

Next, the students practiced drawing conclusions based on the results of their analysis. In addition, they were challenged to solve problems in conventional and innovative ways, thereby encouraging the emergence of creative solutions that differ between groups. The results of the study showed that the Joyful Learning atmosphere successfully built confidence in the students. They felt free to express their opinions, gave each other feedback, and enjoyed the learning process without any pressure. This allowed critical thinking to develop further because the students could openly express their ideas, test their validity, and enthusiastically improve on their shortcomings.

Fourth Step. During the creation phase (Creativity), fourth graders at SDN Masalima IV got the chance to turn the innovative ideas they came up with in the earlier stage into actual projects involving flat building materials. This stage emphasizes the ability of students to think creatively, generates new ideas, expands basic ideas, and applies them in the form of products that can be used in learning. Creativity indicators were clearly visible in this activity. First, the learners created new ideas by designing media or simple works to explain the concept of flat shapes. There was a group that made an interactive geometry board from thick cardboard that could be detached pieces of flat shapes such as squares, rectangles, triangles and parallelograms. This medium was used to visually demonstrate the properties of flat shapes. Secondly, the learners extended the basic idea by adding variations and innovations to the work produced. One group made geometry puzzles from colorful paper and ice cream sticks. The puzzle could be rearranged to form various flat shapes, facilitating learners' understanding of the concept of congruence and differences between shapes.

In terms of art, the students freely designed the products according to their creativity. In this way, simple ideas developed into more creative and applicable media. Third, the learners applied creative ideas in learning. The products created by the students were showcased in front of the class and then reviewed by other groups. For instance, the group that created the puzzle invited others to put the pieces together into a rectangular shape and figure out its perimeter. This activity helped the learners gain a deeper understanding of area and perimeter through hands-on experience with the materials made by their peers. They appeared excited, exchanged feedback, and took pride in the work they produced. The learning environment became more enjoyable as the students not only grasped the theory of flat shapes but also applied it using their own materials.

Fifth Step. During the value stage (Society), fourth-grade students at SDN Masalima IV were encouraged to relate the concept of flat buildings in mathematics to real-life situations. This stage highlights the significance of communication skills, which involve the ability to express ideas and work clearly and coherently so that others can understand. Communication indicators can be observed through various student activities. Firstly, students shared their thoughts and ideas through both oral and written presentations. Each group had the chance to showcase their work, such as geometry board media and flat shape puzzles. The learners explained how these media could help in understanding the concepts of area and perimeter for squares, rectangles, and triangles. Secondly, the learners utilized communication for different purposes, not just to explain mathematical concepts but also to connect them to real-world examples. For instance, one group illustrated that calculating the area of a flat shape

could help determine the number of tiles needed for a house or school floor, or the amount of fabric required to create a flag. Thus, the learners discovered that mathematical communication extends beyond the classroom and is applicable to everyday life. Thirdly, the learners employed various communication media. Besides speaking directly in front of the class, they used posters featuring images of flat shapes or cardboard props with concise explanations. These visual aids enhanced the clarity of their message and made the presentations more engaging and comprehensible for all students.

In summary, the series of the learning activities was conducted following the study's design. Each learning phase was effectively implemented in the teaching and learning process, particularly regarding flat shapes in class IV at SDN Masalima IV. The findings indicated that the students not only achieved a better grasp of mathematical concepts but also engaged actively in activities that foster critical thinking by solving real-world problems (Critical Thinking), expressing ideas both orally and in writing (Communication), collaborating in groups with shared responsibilities (Collaboration), and creating original work as a way to apply the ideas they learned (Creativity). This enabled the students to optimally develop their potential and prepare for global challenges.

The Researchers also conducted interviews with the high, moderate, and low ability learners to obtain a more comprehensive picture of this research. the high ability students stated that STEAM learning based on Deep Learning made the students more enthusiastic in learning, could relate mathematical concepts, especially flat building material, to real life, and were able to develop new ideas independently. In addition, the students also said that group discussions were very helpful in sharpening critical thinking skills and increasing confidence when presenting work results (Communication). The moderate ability learners revealed that learning was easier to understand because of observation, exploration, and real practice activities that made mathematical concepts no longer abstract. They felt more actively involved in group discussions (Collaboration), although sometimes they still needed guidance from teachers and friends to complete the task.

However, they admitted that this method made them more courageous in expressing their opinions and trying to come up with simple creative ideas (Creativity). Meanwhile, the low ability learners said that at first, they found it difficult to follow the learning flow, especially when asked to express their opinions. However, with the division of heterogeneous groups, they were helped by friends who were more capable, so they could learn gradually. They also felt that learning by trying, observing, and making simple works was more fun, so their motivation to learn increased. Overall, the interview results show that the learning process in this study provides a more meaningful learning experience for all students, whether with high, medium or low abilities. Although there are differences in the level of concept mastery, all learners can develop 4Cs skills according to their respective capacities.

At the end of the study, the researchers gave a post-test to all students as an instrument to measure the improvement of abilities after following a series of lessons. This post-test was designed to test students' mastery of mathematical concepts on flat building material while measuring critical thinking skills, ability to convey ideas (Communication), skills to work together (Collaboration), and creativity in solving problems (Creativity). The questions given were not only in the form of counting questions, but also included contextual problem-solving questions that encouraged the students to think more deeply and integrated.

In the beginning, the researchers administered a pre-test to assess the students' initial abilities. The pre-test and post-test results at SDN Masalima IV indicated average scores of 47.19 and 81.67, respectively. This demonstrates an improvement in the 4Cs at SDN Masalima IV following the learning process. Additionally, a normality test was performed as a prerequisite for statistical analysis. Below are the results of the normality test conducted on the research data using SPSS software.

Table 3. Normality Test

Tests of Normality						
	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	Df	Sig.	Statistic	Df	Sig.
Pretest	.143	21	.200	.957	21	.398
Posttest	.126	21	.200*	.968	21	.650

*. This is a lower bound of the true significance.
a. Lilliefors Significance Correction

In the Kolmogorov-Smirnov test, the significance value for both the pre-test and post-test is 0.200, indicating a significance value greater than 0.05, which suggests that the data follows a normal distribution. In the Shapiro-Wilk test, the significance value for the pre-test is 0.398, while the post-test shows a significance value of 0.650. This also indicates a significance value greater than 0.05, confirming that the data is normally distributed. Additionally, the test results were analyzed using the paired sample t-test to assess the impact of the learning implementation on students' 4C abilities. Below are the results of the paired-samples t-test conducted in SPSS.

Table 4. Paired Sample t-test

Paired Samples Test									
		Paired Differences							
					95% Confidence Interval of the Difference				
		Mean	Std. Deviation	Std. Error Mean	Lower	Upper	T	df	Sig. (2-tailed)
Pair 1	Pre-test – post-test	-34.48	7.2	1.59	-37.85	-31.10	-21.58	20	.000

The output shows $Sig.\,(2-tailed)$ of 0.000 < 0.05, which indicates a significant difference between the pre-test and post-test results. Therefore, it can be concluded that Deep Learning-based STEAM learning has an effect on the 4Cs abilities of the students in grade IV at SDN Masalima IV.

Based on the findings from the mixed-method research conducted, it can be concluded that the implementation of Deep Learning-based STEAM learning significantly enhances the students' 4Cs skills. The quantitative data analysis reveals measurable and significant improvements in learning outcomes, while the qualitative analysis indicates shifts in behavior, attitudes, and skills that are pertinent to the demands of the 21st century. These findings affirm that Deep Learning-based STEAM not only boosts academic performance but also cultivates vital 21st-century competencies among students. This aligns with research indicating that the integration of STEAM, based on local culture and ethnomathematics, can enhance numeracy literacy and fulfil the Pancasila Student Profile (Aini et al., 2025). This model presents an innovative alternative for educational practices in other schools that possess local potential for integration into the learning framework.

4. CONCLUSION

According to the research findings, it can be concluded that each step of STEAM learning (Observe, New Idea, Innovation, Creativity, Society) has been implemented sustainably and has effectively contributed to the development and enhancement of the students' critical thinking skills, specifically in Communication, Collaboration, and Creativity (4Cs). The students demonstrated advancement in critical thinking by analyzing problems and formulating logical arguments that incorporate multiple disciplines. Their communication skills have also enhanced, as evidenced by their increased confidence in articulating ideas, engaging in discussions, and responding to peers' viewpoints in a more organized way. Regarding collaboration, the learners are becoming accustomed to teamwork, sharing responsibilities, and effectively completing group projects. Furthermore, the students' creativity is fostered through a range of innovative projects that merge the principles of science, technology, art, and values pertinent to their everyday experiences. The analysis of the pre-test and post-test results

revealed a substantial increase of 47.19 and 81.67, respectively. The results of the normality test indicate that the data follow a normal distribution, while the paired sample t-test yields a significance value of 0.000 (<0.05). This signifies a notable difference in learning outcomes before and after the implementation of the learning strategy, demonstrating the impact of STEAM-based Deep Learning on students' abilities in Critical Thinking, Communication, Collaboration, and Creativity (4Cs).

Based on the findings from the conducted research, there are recommendations that future researchers should consider. This study is limited to a relatively small sample size and specific areas, which means the results cannot be broadly generalized. Consequently, it is suggested that future researchers broaden their research scope by including a larger sample size and a more varied school context, taking into account different educational levels and socio-cultural backgrounds, to gain a more thorough understanding of the effectiveness of Deep Learning-based STEAM implementation. Furthermore, this research primarily concentrated on enhancing 4Cs skills through short-term learning projects. In future developments, researchers could create STEAM-based learning models utilizing a Deep Learning approach over an extended period, allowing for a deeper understanding of the sustainability of their impact on students' attitudes, skills, and learning outcomes.

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