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Critical thinking and creativity in STEAM-based collaborative learning on renewable energy issues

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ABSTRACT

Renewable energy is a global concern and should be incorporated into education to raise awareness among younger generations, including in physics education. Educators have made various efforts to raise awareness of the importance of pursuing renewable energy. A breakthrough sought in this research is to incorporate collaborative learning into the science-technology-engineering-art-mathematics (STEAM) approach. Integrating STEAM into collaborative learning can simultaneously develop critical and creative thinking skills by exploring local resources to become renewable energy sources. The research involved 36 high school students who met the criteria for having a smartphone and accessing a reliable internet connection. These conditions are designed to facilitate students' producing essays and posters exploring renewable energy sources in their local area. The research design employs a one-group pretest-posttest approach to assess the effectiveness of this STEAM-based collaborative learning process. The data collected from tests that have undergone t-tests and N-gain analysis, triangulated with observation data and questionnaires, illustrates the progress made in improving students' critical and creative thinking abilities. In conclusion, the implementation of STEAM-based collaborative learning demonstrates the highest level of achievement in creative thinking. It enables the production of innovative mini-projects that critically analyze local resources available for national energy sources.

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1. INTRODUCTION

The pandemic has brought attention to the current economic crisis, as there is a surge in demand for energy supplies while quotas remain unchanged. Due to the energy resource crisis, this has led to an increase in the prices of essential goods. The energy crisis has profoundly impacted Europe, Asia, and America and is currently the subject of widespread discussion. The transition to green energy poses a significant challenge. Reduction of emissions, particularly from the energy sector, is a priority for many countries. China is closing hundreds of mines, cutting production from coal-fired power plants, and implementing renewable energy sources [1]. Several European countries, including England, are experiencing an energy crisis [2]. European and British governments have implemented measures to reduce emissions by decommissioning coal power plants and transitioning to natural gas as the primary energy source [3]. Despite this effort, natural gas supplies have struggled to meet demand due to production shutdowns in the US and supply constraints in Russia [4]. Energy plays a crucial role in sustaining life. Energy consumption during 2000-2009 rose from 709.1 million barrels of oil equivalent (BOE) in 2000-865.4 million BOE in 2009, with an average increase of 2.2 per year [5]. The industrial sector has the highest final energy consumption, followed by the household and transportation sectors. In line with this issue, a need for more existing energy resources will render Indonesia incapable of meeting its domestic energy production requirements by 2030 [6]. The condition requires capable human capital that is skilled and innovative to generate ideas for exploring alternative energy resources.

High school students will be crucial in managing future economic, social, and industrial sectors in the next decade. It is advisable to involve them in taking action from their perspectives to become responsible individuals in preserving energy resources. This is to understand that education for sustainable development instills in individuals the knowledge, skills, attitudes, and values necessary to fashion a sustainable future [7]. Engaging technology in high school physics learning to foster a better understanding of renewable energy is an effective and progressive effort.

The technological advancements in this decade demonstrate that the world and education are progressing rapidly. Efforts have been made in education to develop students' technical abilities through every curriculum update initiated by the government. The aim is to create a reliable and prepared generation that is competent in globalization. A learning approach that accommodates the skills required for the 21st century is available. Involving technology in learning will make it easier for students to access information about renewable energy sources around their environment. Through technology, it will also be easier for teachers to encourage students to be more critical in managing information and more creative in presenting meaningful information. A multidisciplinary approach is required to achieve this goal and ensure that students comprehensively understand renewable energy sources.

Science-technology-engineering-art-mathematics (STEAM)-based learning integrates scientific disciplines into a unified education approach, including science, technology, engineering, art, and mathematics. Using STEAM as a learning approach will allow students to generate innovative ideas about renewable energy resources through problem-solving activities rooted in these five integrated scientific fields. Problem-solving based on multiple scientific disciplines can produce comprehensive solutions, addressing mathematical problems and incorporating concepts from related scientific domains. Integrating STEAM learning ensures students can solve problems effectively and fosters creativity, enabling them to confront future challenges [8].

Acquiring critical thinking, creativity, communication, and collaboration skills are deemed essential components of contemporary education in the 21st century [9]. Students' collaborative skills also enhance critical thinking, creativity, and 21st century skills [10]. Collaborative skills include critically solving problems, generating innovative ideas, and effectively articulating them in oral or written form within a dynamic group. One of the collaborative skills-based learning models is the STEAM-based collaborative learning model. Collaborative learning allows students to engage in activities with peers to solve contextual issues, such as educational and economic problems. The learning models proposed strengthen the student's ability to handle situations and support students in developing their capabilities to make strategic decisions. Moreover, the learning model can enhance students' critical thinking skills [11] and improve their creative thinking abilities [10]. Based on this explanation, implementing STEAM-based collaborative learning has great potential for educating students on how to address issues related to developing renewable energy sources in their local communities.

STEAM-based collaborative learning denotes project-based learning incorporating provisions from all five STEAM disciplines. Implementing STEAM-based collaborative learning with mini-projects expands the benefit of enhancing students' critical and creative thinking skills [11]. Research suggests that engaging in project activities in STEAM-based collaborative learning can foster innovation, thereby facilitating the development of students' creative thinking [12]. Innovative individuals are inclined toward generating novel concepts and inventive approaches to devise practical solutions. This approach highlights the significance of offering students chances to enhance their critical and creative thinking skills by engaging in collaborative work on small projects, such as proposing ideas for managing renewable energy sources. The research question can be formulated based on the background information: "How does collaborative learning based on STEAM influence students' critical and creative thinking abilities on renewable energy issues?" This study examines the impact of STEAM-based collaborative learning in enhancing students' critical and creative thinking abilities on renewable energy issues.

2. METHOD

STEAM learning enhances students' creative abilities by enabling them to think creatively, explore, observe, reflect, and pose unconventional questions within a supportive environment [13]. Creativity can be imparted by setting and practicing an example [14]. Consequently, teachers must demonstrate creative values and behavior while encouraging a positive classroom atmosphere. The stages of learning with a collaborative-based STEM approach are supported by the presence of modules to guide student activities. This module contains systematics that provide an overview of the STEM components trained in student activities while learning about renewable energy (Table 1). Teachers guide students in learning renewable energy topics by raising energy scarcity issues and making them aware of energy sources that can be developed in Indonesia. Students also have the opportunity to work in groups to discuss renewable energy sources in their neighborhood. Students are shown the forms of renewable energy being developed today. They are asked to produce a digital poster showing ways of using the natural resources from their environment that they have identified as having the potential to be processed into renewable energy.

Table 1. STEM components trained in student activities while learning about renewable energy

E-module content	STEAM aspects
There is a short reading and a QR code about one of the energy sources	Science, Engineering, Mathematics
Availability of images on the impact of energy sources and green technologies	Technology, Art
Examples and practice questions on energy sources	Science, Mathematics, Engineering
Assignment activities to create posters about energy sources or the greenhouse effect using Canva	Science, Technology, Engineering, Art

This research involved 36 high school students. This sample was selected because all students have smartphones, compared to other classes within the same population [15]. The research used a one-group pretest-posttest design. The sample in this study involved 16 male students and 20 female students. The sample in this research used the purposive sampling technique [16]. The purpose of the sampling technique is based on the availability of Wi-Fi in the classroom and the use of smartphones by all students. Research data was obtained using written tests and observation sheets. Data on creative thinking and critical thinking skills were obtained from the pretest and posttest results, which were assessed using the creative thinking and critical thinking skills assessment rubric. The test instrument for critical thinking consisted of 14 questions, five for high and medium validity categories and 4 for low validity. The instrument has undergone reliability testing and achieved an Alpha Cronbach score of 0.89. The test instrument for creative thinking consisted of eight questions, one for the very high validity category and seven for the high validity category. The instrument has undergone reliability testing and achieved an Alpha Cronbach score of 0.95. The indicators in Table 2 for evaluating creative thinking skills are a modification from the main aspect of Munandar's creative thinking [17]. The indicators for assessing critical thinking skills use the indicators from Ennis [18] presented in Table 3.

Table 2. Creative thinking indicators adapted from Munandar

Creative Thinking Skills Aspects	Creative Thinking Skills Indicator
Originality	Thinking differently from others Finding new ideas
Fluency	Having lots of ideas
Flexibility	Giving a variety of opinions Giving different considerations to others
Elaboration	Detailed performance

Table 3. Critical thinking indicators adapted from Ennis

Critical Thinking Skills Aspects	Critical Thinking Skills Indicator
Providing basic explanations	Focusing questions Analyzing the question Asking and answering
Building basic skills	Considering the credibility of the source
Drawing conclusion	Composing and considering deductions Drafting and considering inductions
Providing further explanation	Identifying terms and considering definitions Identifying assumptions
Organizing strategy and tactics	Defining an action and interacting with others

The study was analyzed using IBM SPSS Statistics 22. Test instruments were employed to measure the students' critical thinking abilities, and the collected data was assessed for normality. The Chi-Square statistics method was used to carry out the normality test on the data from this study. It was discovered that the calculations were less than Chi-Squared, indicating that the data conforms to a normal distribution. The data analysis technique uses the t-test and N-gain score test. The N-gain Score test aims to determine the effectiveness of collaborative learning on student character development through a pretest-posttest instrument. N-gain Score can be calculated using the formula according to Hake (1) [19].

$$\langle g\rangle = \frac{\langle S_{po}\rangle - \langle S_{pe}\rangle}{S_{id} - \langle S_{pe}\rangle} \quad (1)$$

Where ⟨g⟩ is the N-gain score, $\langle S_{po}\rangle$ is the score of posttests, $\langle S_{pe}\rangle$ is the score of pretests, $\langle S_{id}\rangle$ is an ideal score (100). Table 4 is shown the N-gain score categories

Table 4. N-gain score categories

N-Gain Score	Categories
$\langle g\rangle \leq 0.30$	Low
$0.30 < \langle g\rangle \leq 0.70$	Moderate
$\langle g\rangle > 0.70$	High

3. RESULTS AND DISCUSSION

This study examines the impact of training critical and creative thinking skills simultaneously through collaborative learning with a STEAM-based approach. Previous studies have only partially explored the effects of practicing critical or creative thinking skills alone. They have yet to be involved in mini-projects that have become national issues, such as recognizing renewable energy sources in students' local communities. Thus, this could be a breakthrough in raising students' awareness of their role in considering the sustainability of future energy sources.

3.1. Critical thinking abilities after collaborative learning

A paired samples t-test is conducted, and the results of the t-test analysis show that $t_{count\,(3.668)} > t_{table(2.042)}$, which proves that the collaborative learning model applied with the STEAM approach has provided a significant difference from the average pretest and posttest scores. This has implications for the effectiveness of using the model to train students' critical thinking skills.

The improvement in students' critical thinking abilities is apparent in the N-gain test, depending on their pretest (left bars) and posttest (right bars) scores of each category, as shown in Figure 1. Based on the data presented in Figure 1, the overall N-gain score is 0.31, with moderate criteria. The data shows that the ability to analyze questions, compile and consider deductions, and identify assumptions achieved must still be pursued to be more optimal. This study only occurs in three meetings, but students have shown indications of positive change. However, further and in-depth studies may be needed to confirm whether it will increase even more by consistent assistance in carrying out the stages of the collaborative learning model with the STEAM approach.

The analysis of N-gain for critical thinking skills indicates that organizing strategies and tactics have the highest N-gain value compared to the other five elements. The data presented demonstrates that students' identification of energy sources in their local communities has facilitated critical thinking regarding their renewability. We found that training students to identify fundamental concepts of renewable energy sources has encouraged them to apply these characteristics to the types of alternative energy sources they discover on the internet about potential resources in their local communities. This aligns with research results that show that relating learning context to everyday life events can improve students' understanding of concepts [20], [21]. The proposed learning method in this study tended to have a portion of discussions occur in groups to analyze and decide about the categories of alternative energy sources as renewable.

In the STEAM-based collaborative learning, students were asked to express their findings on data about energy problems and potential energy sources in their local communities, along with their reasons and supporting data, in the form of article writing. Writing activities such as papers can support students' critical thinking skills [22]. In making the papers, students learn how to think critically about the problems faced and provide solutions to these problems in the form of documents [23]. However, the aspect of composing and considering deduction and identifying assumptions has decreased. This happens when the group identifies an assumption and may become fixated on a particular assumption, leading to inaccurate information. The statement assumes that all alternative energy is renewable when, in fact, the correct concept is that all renewable energy is part of alternative energy.

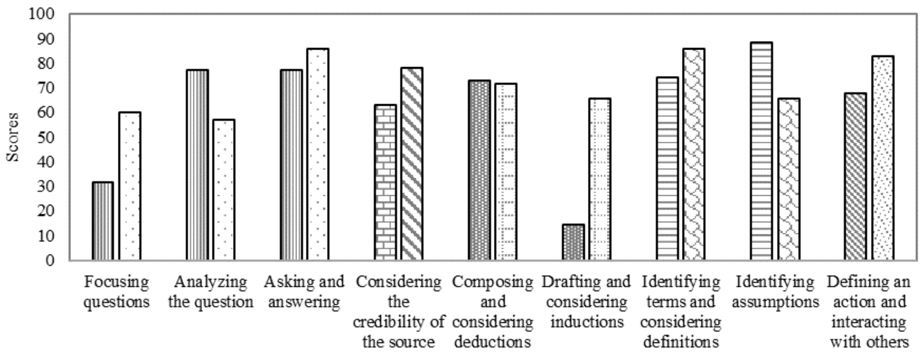

Figure 1. N-gain analysis of each aspect of critical thinking

We found that writing papers activities are a solution provided by students to existing problems. The essence of writing a paper is explaining and solving the problem. Through this activity, students also practice sorting and selecting accurate information from the internet and supporting alternative ideas for problem-solving solutions. This data is strengthened by evidence that delivering essential explanations and providing further explanations reach the highest score among the five other elements of critical thinking. Our findings prove that using internet technology to write papers on renewable energy contexts facilitates students' ability to determine the theme and dense, informative, and readable content.

3.2. Creative thinking ability after collaborative learning

Students' creative thinking skills measured from the t-test analysis in renewable energy contexts were at $t_{count\ (4.744)} >, t_{table(2.042)}$, which indicates that implementing the collaborative learning model has positively impacted the development of creative thinking skills.

The student's creative thinking skills increase in the N-gain test based on each category's pretest (left bars) and posttest scores (right bars). At the beginning of the session, we found that the ability to focus on questions, drafting, and considering inductions could have been more evident. However, collaborative work facilitates problem-solving activities and encourages students to express their opinions, leading to peer learning. The N-gain analysis of each aspect of creative thinking skills is shown in Figure 2.

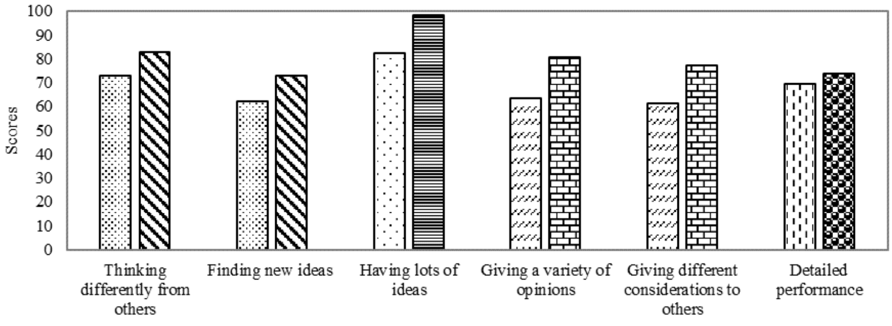

Figure 2. N-gain analysis of creative thinking aspects

Creative thinking skills in this research were developed through project activities to make digital posters using Canva. Based on the data in Figure 2, the N-gain calculation was obtained at 0.40, which is included in the moderate category. We found that creating digital posters is an activity that gives them space to express their ideas by exploring Canvas features to present information creatively. They can identify energy sources that have the potential to be optimized into alternative renewable energy sources. They can also provide color contrast, design, font type, and font size as a viable way to produce creative products due to their entity as Gen-Z, who quickly adapt to digital technology. In this section, the STEAM approach takes the role optimally. Students learn not only the context of renewable energy but also how to convey ideas in an attractive, persuasive way with the support of convincing data.

The N-gain score for the fluency aspect received the most considerable N-gain value among the four elements of creative thinking. This is characterized by students being able to find answer ideas or think of more than one answer to solve problems. This activity has a positive impact, so students can answer the posttest much better. In line with research results, students with fluent thinking skills can ask several questions, are adept at conveying ideas or ideas, and can think faster than students in general [24]. The data is the research results that show that making posters can support students' creative thinking skills [25] and accommodate students' innovative ideas in the making process [26], [27].

The activity of creating digital poster works is aimed at improving students' creative thinking skills. This is indicated by the acquisition of scores for fluency thinking skills, obtaining the highest score among the four other elements of creative thinking. It strengthens the theory that students can provide many ideas by making posters. The ideas in the poster contain information and raise current topics; the information provided should be discussed [28], [29]. Making posters is one of the research activities that supports the development of student character, especially the character of creative thinking. This finding is supported by the research revealing that poster-making by students utilizing Canva media measures student creativity using assessment aspects, including content/text, message delivery, design, images, many ideas, and STEAM elements [30].

4. CONCLUSION

The study investigates enhancing critical thinking skills through mini-projects involving article writing and creative thinking skills through poster-making activities using Canva. The implementation of collaborative learning has helped students solve problems together, and peer learning takes place, which improves students' critical and creative thinking. The results of enhanced critical and creative thinking demonstrate the effectiveness of each activity. The topic of renewable energy provides an opportunity for students to recognize the importance of preparing alternative energy for the future and work together to solve problems critically and creatively. Otherwise, additional and comprehensive research may be necessary to verify its efficacy, particularly regarding the saturation of the topic and the innovation of mini-project activities.

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