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Implementation of STEM-EDP Approach Based on SDGs to Improve Critical Thinking Skills (Topic: Global Warming)

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Abstract

Thinking critically is essential in the 21st century to solve complex global problems. However, students' lack of critical thinking skills regarding real-world issues such as global warming needs to be addressed. This study examines the increase in students' critical thinking using STEM-EDP based on the Sustainable Development Goals (SDGs) in global warming materials. Conducted at one of the senior high schools in Samarinda, this study used a group pretest-posttest design with 35 students in class X. The validity instrument used was deemed appropriate by science education experts, and its reliability coefficient was 0.75. Data were collected through critical-thinking tests before and after treatment and analyzed using N-Gain and paired t-tests. Results show STEM-EDP improves critical thinking: the average pretest was 33.10, increasing to 61.92 in the posttest. The N-Gain value of 0.43 is moderate, with the highest increase in hypothesis testing. The paired t-test shows a Sig. of 0.000 (<0.05), indicating a significant difference between the pretest and the posttest. In conclusion, STEM-EDP improves students' critical thinking skills on global warming material. However, posttest scores indicate that skills remain adequate, underscoring the need for further evaluation and improvement of STEM-EDP implementation. The findings of this study can serve as a basis for further investigation by other researchers into which STEM-EDP steps have the greatest impact on critical thinking.

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INTRODUCTION

Learning in the 21st century focuses on developing students' skills that also support the achievement of the Sustainable Development Goals (SDGs). The goal is for students to contribute meaningfully to the community's life (Agirreazkuenaga, 2019; United Nations, 2015). The SDGs are sustainable development agreements divided into four areas: economic, social, institutional, and environmental (Amato & Korhonen, 2021; Fadel, 2010; Tu et al., 2023). One of the main focuses in the SDGs is the 13th goal, which addresses climate change with three primary targets: strengthening resilience and adaptation capacity to climate disasters, integrating climate change actions in national policies, and increasing education and awareness of climate change mitigation and adaptation (Demaidi & Al-Sahili, 2021; United Nations, 2015).

Global warming is a problem experienced by all living creatures on Earth, characterized by a rise in average air temperatures on land and in the oceans, as well as by unpredictable weather conditions (Pinontoan et al., 2022). Global warming is the phenomenon of rising global surface temperatures that has been occurring since the 19th century, primarily due to human activities such as the burning of fossil fuels and changes in land use (Intergovernmental Panel on Climate Change, 2022). Global warming is a global phenomenon caused by human activities, particularly those related to the use of fossil fuels and land-use changes. These activities produce greenhouse gas emissions that accumulate in the atmosphere in ever-increasing quantities, thereby intensifying the greenhouse effect (Damayanti et al., 2023).

Indonesia ranks sixth worldwide in carbon emissions, which contribute to global climate change (Harris & Sargent, 2016; Ramadhan et al., 2025). Climate change has become a critical global issue due to its profound impacts, including disturbances to the natural balance, sea-level rise, and forest fires, which threaten human survival worldwide (Efwinda et al., 2023; Ratinen, 2021). For this reason, with respect to goal 13, Indonesia has taken strategic steps to increase adaptation capacity and to include climate change anticipation policies in national development plans (Bappenas, 2019; Ratnasari & Nugraheni, 2024). However, if teachers remain the center of attention during the learning process, this may prevent students from having the opportunity to practice their critical thinking skills (Mardiana et al., 2025; Sujanem & Putu Suwindra, 2023). In fact, critical thinking is essential for students to understand problems, find root causes, and find solutions (Purwanto et al., 2019; Wayan Suastra & Ristiati, 2019). The low level of students' critical thinking skills in schools is due to teaching materials and learning approaches that are less engaging and less innovative (Ananda et al., 2023; Mao et al., 2022; Wayan Suastra & Ristiati, 2019; Wibowo et al., 2024). This also has an impact on students' lack of ability to reason critically. Therefore, teachers need to develop innovations in learning and design teaching materials that can encourage students to think critically through questions with diverse cognitive domains.

The STEM learning approach, combined with the Engineering Design Process (EDP), has significantly improved students' critical thinking skills through involvement in real-world problem-solving and product development (Cyndirela et al., 2025; Safitri et al., 2024). The development of students' critical thinking skills can be achieved through effective learning planning, including the application of the Engineering Design Process (EDP) approach, which is closely related to the STEM approach (Safitri et al., 2024; Wibowo et al., 2024). The EDP stages, which include define, learn, plan, try, test, and decide, allow for the development of critical and creative thinking skills in a structured manner (Cyndirela et al., 2025; Putra et al., 2023).

Based on interviews with teachers at one of the senior high schools, students' critical thinking skills are still low. When answering questions, many students imitate books or teachers' explanations without developing their own thoughts. The findings of this interview are consistent with several studies in Indonesia that have also shown that students' critical thinking skills are generally still low (Anggraini et al., 2025; Ardiyanti & Nuroso, 2021; Sulbiana et al., 2024).

Several studies integrating the STEM approach with the Engineering Design Process (EDP) Model have successfully demonstrated that implementing this model can enhance or influence students' critical thinking skills. For example, a quasi-experimental study conducted by Safitri et al. (2024) showed that a STEM-based EDP model for high school students can improve their critical thinking skills, particularly regarding environmental pollution. Additionally, a study conducted by Sapphira & Sari (2023) also successfully demonstrated the impact of the STEM-based EDP model on students' critical thinking skills regarding vibration, as well as a study by Rahman (2022) on the excretory system. Therefore, this study aims to examine whether implementing SDG-based STEM-EDP on

climate change can also improve students' critical thinking skills. The formulation of the problem in this study is 1) What are students' critical thinking skills before and after the implementation of the SDG-based STEM-EDP approach in the global warming curriculum? and 2) To what extent have students' critical thinking skills improved following the implementation of the SDG-based STEM-EDP approach in the global warming curriculum?

METHODS

This study uses a pre-experimental design with a one-group pretest-posttest. The research sample consisted of one class, namely class X-C at one of the senior high schools, with 35 students. The research was carried out in the high school's even semester of the 2024/2025 school year. Purposive sampling was used at the teacher's recommendation because the class had sufficient time for physics and was homogeneous. Data were collected through a critical thinking ability test in the form of 10 multiple-choice questions and four essay questions given before and after the treatment. The questions cover several indicators of critical thinking, such as hypothesis testing, argument analysis, and analysis of possibilities and uncertainties, as well as problem-solving and decision-making. The instrument was validated by experts, including 2 science education lecturers and 3 science teachers, and was deemed suitable for use as a critical thinking skills test. After validation, the instrument was tested for reliability, yielding a reliability coefficient of 0.75, which falls into the high category.

The treatment was in the form of a learning experience based on the SGD-based STEM-EDP approach, using materials on global warming. The final critical thinking score obtained will be adjusted to the category of value interpretation in Table 1.

Table 1 Pretest and posttest assessment categories

No.	Score (1-100)	Category
1.	$80 < x \leq 100$	Very High
2.	$70 \leq x \leq 80$	High
3.	$60 < x \leq 70$	Medium
4.	$40 < x \leq 60$	Low
5.	$0 \leq x \leq 40$	Very Low

Data analysis involved calculating pretest and posttest scores, then using the N-Gain test to assess the level of improvement in students' critical thinking and the paired-samples t-test to determine the significance of the pre- and post-treatment differences. Before conducting the hypothesis test, a Shapiro-Wilk normality test was performed to ensure the data were normally distributed. The hypothesis tested is whether applying the STEM-EDP approach significantly improves students' critical thinking skills. The N-gain value results will be adjusted to the interpretation category (Hake, 1999) in Table 2.

Table 2 N-gain value criteria

N-Gain Value	Criterion
N-Gain ≥ 0.70	High
$0.70 >$N-Gain ≥ 0.30	Medium
N-Gain < 0.30	Low

RESULTS AND DISCUSSION

In this study, a significant increase was observed after applying the STEM-EDP approach to materials on global warming. The SDGs-based STEM-EDP approach is applied to materials on global warming.

Condition of Students' Critical Thinking Ability Before and After Treatment.
The research was conducted across five meetings, beginning with a pretest and ending with a posttest, to measure students' critical thinking skills. The graph of the pretest and posttest assessment results is shown in Figure 1.

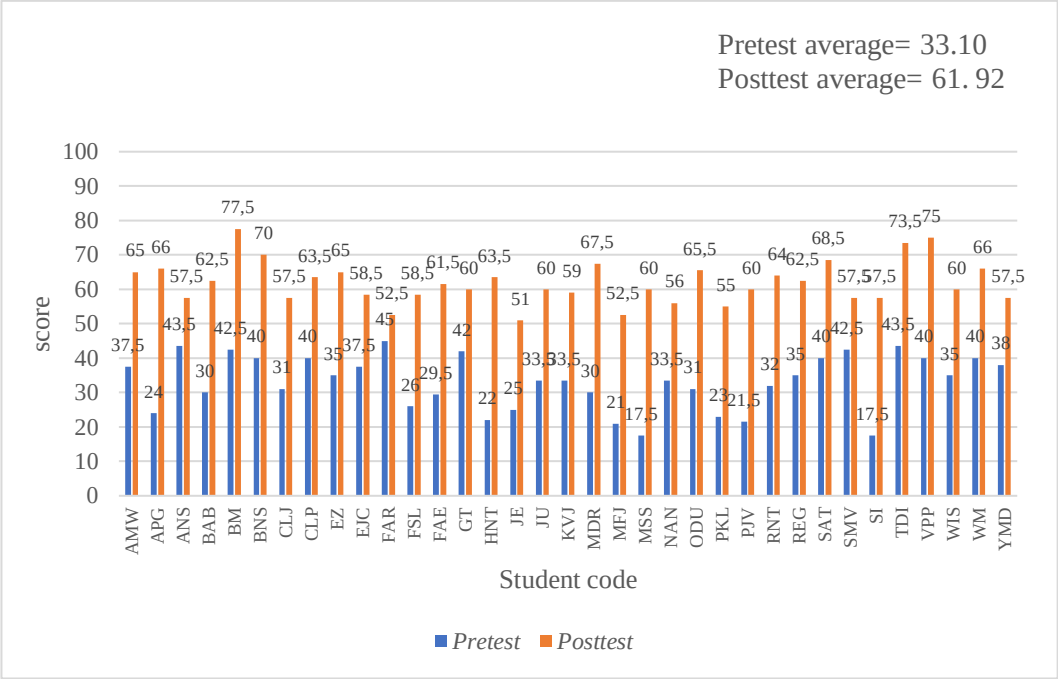

Figure 1 Critical thinking pretest and posttest results

Figure 1 shows the pretest and posttest results for students' critical thinking skills before and after the intervention, which involved implementing the STEM-EDP approach, with scores ranging from 17.5 to 45. Then, after treatment or a posttest, the results were scored in the range of 51-77.5. The following are the average results for the pretest and posttest, as presented in Table 3.

Table 3 Average results of pretest and posttest

	Description				
	N	Minimum	Maximum	Mean	Std. Deviation
Pretest	35	17.5	45	33.10	7.970
Posttest	35	51	77.5	61.92	6.161
Valid N (listwise)	35				

Based on the analysis, students' critical thinking skills before implementing the SDGs-based STEM-EDP approach were relatively low, with an average pretest score of 33.10. After being given treatment, the average posttest score increased to 61.92. This improvement shows that the STEM-EDP approach can facilitate students in understanding the material of global warming while also practicing their critical thinking skills.

The pretest results showed that most students were in the "very low" and "low" categories. After learning, posttest results showed a significant improvement, with most students in the "medium" and "high" categories.

Improving Students' Critical Thinking Skills
To assess learning outcomes before and after the implementation of SDGs-based STEM-EDP, the N-Gain test was administered using IBM SPSS Statistics 25. The results of the N-gain value are presented in Table 4.

Table 4 Results of n-gain value acquisition

Average Pretest	Posttest Average	N-Gain	Criterion
33.10	61.92	0.43	Medium

Table 4 shows that implementing STEM-EDP effectively improves critical thinking skills. However, its application still needs to be optimized so that students can achieve improvement in the high category.

The criteria for improving students' critical thinking skills were assessed using N-Gain analysis based on pretest and posttest results for each student, and the results are presented in Table 5.

Table 5 N-gain criteria for improving critical thinking skills are presented

N-Gain Value	Criteria	Frequency	Percentage
N-Gain ≥ 0.70	High	0	0
0.70 >N-Gain ≥ 0.30	Medium	32	91.43
N-Gain > 0.30	Low	3	8.57

The results of the N-Gain test of data distribution showed that 91.43% of students were in the medium category, 8.57% in the low category, and none in the high category. This indicates that implementing STEM-EDP is quite effective in improving critical thinking skills. However, its application still needs to be optimized so that students can achieve improvement in the high category.

The implementation of the STEM learning approach that integrates the EDP and the SDGs in this study aims to develop students' critical thinking skills in solving real-world problems related to sustainable development. This approach utilizes the EDP cycle model, comprising the stages of observation, design, testing, and evaluation, as an integrated learning method within the STEM context, with a focus on SDG issues.

In this study, students were introduced to the issue of global warming and its various impacts. They were asked to design and create a simple project illustrating efforts to adapt to and mitigate global warming. One example of a global warming mitigation and adaptation project created by students in their groups is a miniature eco-friendly house. Students designed energy-efficient homes with natural lighting and ventilation, considering building height, the number and arrangement of windows and doors, the use of renewable energy sources through solar panels, and the use of eco-friendly and recyclable materials. Students' critical thinking skills improved because the design-and-evaluation process using the STEM-EDP approach deepened their understanding of environmental issues, including global warming. Students' understanding of global warming material during the learning process was evident from their completion of student worksheets at each session, which were designed to align with critical thinking indicators linked to the steps of the STEM-EDP approach.

The students' critical thinking skills improved after the intervention. This is evident from the higher average posttest scores compared to the average pretest scores, as shown in Figure 2 and Table 3. This approach enables students to develop critical thinking through a structured learning process. The STEM-EDP learning approach is designed to encourage students to actively observe, analyze, design, create, test, evaluate, and reflect on their learning outcomes in a collaborative and creative manner. The STEM-EDP approach effectively trains students to think critically through real-world problem projects (Aini et al., 2025).

The pretest and posttest data collected from the students were then analyzed using the N-Gain test. The N-Gain test was administered to assess the extent of improvement in students' critical thinking skills before and after instruction using the STEM-EDP approach. Table 4 presents the results of the N-Gain analysis, which indicate that the SDGs-based STEM-EDP approach can improve students' critical thinking skills in the medium

category. This result aligns with Wibowo et al.'s (2024) research, which also states that integrating the STEM approach into EDP can enhance students' critical thinking skills in problem-solving and solution-finding. Research by Muyassaroh et al. (2022) shows that STEM-based learning activities help students learn to work together in teams, share ideas, and build solutions, thereby improving their collaborative skills. Ramli's (2024) assertion that STEM-EDP instruction enhances students' critical thinking skills: the STEM-EDP approach effectively trains students to think critically through real-world problem-based projects.

Learning through the STEM-EDP approach can be an effective way in improve critical thinking skills. In the implementation of this study, the STEM-EDP approach enabled students to identify, formulate, and test hypotheses based on available data or information, as well as through real-world scenarios, data tables, graphs, and case studies, encouraging students to make predictions, analyze cause-and-effect relationships, and draw conclusions based on empirical evidence. This aligns with research conducted by Asimakopoulou et al., (2021), who stated that STEM-EDP can contribute to critical thinking indicators such as hypothesis testing due to the highly contextual nature of STEM-EDP learning and its focus on real-world experiences, where students are actively involved in designing, testing, and validating hypotheses using concrete data and information (e.g., data tables, graphs, and real-world case scenarios).

Applying the STEM model to learning materials effectively enhances students' problem-solving skills and confirms that the STEM approach supports the development of critical thinking skills in solving complex problems (Hebebci & Usta, 2022; Purwaningsih et al., 2020; Topsakal et al., 2022). In the topic of global warming, a subject that directly involves data, phenomena, and cause-and-effect relationships, students will also make decisions based on concrete evidence. SDG-based STEM-EDP learning using global warming as a topic enhances students' understanding of the SDGs and their critical thinking skills. It also helps students grasp mitigation and adaptation efforts regarding global warming through a miniature eco-friendly house project. SDG 13 focuses on climate action, where, in the global warming curriculum, students are taught to understand the causes, impacts, and solutions related to global warming so that they become aware and take responsibility for protecting the Earth. The STEM-EDP approach to learning uses the engineering process to solve problems, with students using science to understand the phenomenon of global warming and technology and engineering to design solutions by creating miniature eco-friendly houses.

CONCLUSION

Based on the results of the research and data analysis conducted, it was concluded that students' critical thinking skills before and after the implementation of the SDGs through the STEM–EDP approach in the global warming curriculum were 33.10 on the pretest (in the "low" category) and 61.92 on the posttest in the "medium" category. Furthermore, there was an improvement in students' critical thinking skills following the implementation of the SDGs through the STEM–EDP approach on the topic of global warming, which fell into the medium category. A limitation of this study is its use of a one-group pre-test-post-test design, which is inherently weak because it lacks a control group. Although this study indicates that the approach can improve students' critical thinking skills, the average scores were only moderate. Further evaluation and research are needed to determine which stages of this approach are most effective in enhancing students' critical thinking skills.

CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest.

AUTHOR CONTRIBUTIONS STATEMENT

Conceptualization, SE and MS; methodology, SE, NFS, and LS; formal analysis, SI, MS, AH, NFS, and LS; writing—preparation of the original draft, SI; and finalization, SE, MS, AH, NFS, and L.S.

AI DISCLOSURE STATEMENT

The authors utilized ChatGPT to identify relevant references from reliable articles, thereby enriching the existing literature. The authors reviewed the recommended references and used only those that were relevant. The authors also used Grammarly to refine the English in this article. The authors take full responsibility for the final version of this article and its originality.

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