Jurnal Penelitian dan Pembelajaran IPA JPPI
Vol.10, No.1, 2024, p. 115-145 p-ISSN 2477-1422 e-ISSN 2477-2038

STEM ESD-Based Learning with "Arduino Uno-Based Trash Can" to Improve Students' Critical Thinking Skills and Sustainable Awareness in Learning Environmental Pollution

(Received 16 January 2024; Revised 31 May 2024; Accepted 31 May 2024)

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DOI: 10.30870/jppi.v10i1.24008

Abstract

STEM ESD-based learning with "Arduino UNO-Based Trash Can" is a learning model that integrates STEM learning with the principles of Education for Sustainable Development (ESD). ESD recognizes critical thinking and sustainable awareness as the competencies that help develop one's personal qualities for tackling sustainability challenges in the future. Therefore, this research investigated whether STEM ESD-based learning with "Arduino UNO-based Trash Can" improves students' critical thinking skills and sustainable awareness in learning about environmental pollution. A pre-experimental design with one group pretest-posttest design was employed. The participants in this research study were thirty-six 7th-grade junior high school students in one public school in Subang. Critical thinking skills were assessed through ten essay questions and evaluated using a rubric on a scale of zero to three. Sustainable awareness was measured by a 4-point Likert scale questionnaire comprising 27 statements. Data from both instruments were analyzed using IBM SPSS Statistics software. The results showed that the STEM ESD-based learning with "Arduino UNO-Based Trash Can" contributed positively to improving students' critical thinking skills. However, the improvement was not uniformly distributed among all indicators and remained low, with 0.202 of the N-Gain score. On the other hand, the study revealed that the STEM ESD-based learning with "Arduino UNO-Based Trash Can" did not significantly improve students' sustainable awareness, with only a 0.040 N-Gain score. This study's results contribute to future research or teaching as references for integrating STEM learning with ESD in presenting environmental pollution in the context of sustainability.

Keywords: Critical Thinking Skills, Environmental Pollution, STEM ESD-Based Learning, STEM, Sustainable Awareness

INTRODUCTION

Education for Sustainable Development (ESD) is a crucial solution for tackling sustainability challenges in the future world (Pauw et al., 2015). The goal is recognized as a key to achieving the Sustainable Development Goals (SDGs) and creating a more sustainable world (Ssossé, Wagner and Hopper, 2021). SDG's goal number 4 ensures inclusive access to quality education and lifelong learning opportunities for all (UNESCO, 2017). Empowering younger generations with ESD prepares them for proactive response to future environmental changes by equipping them with knowledge, skills, values, and attitudes for creating a sustainable future (Draghici, 2019). Hence, it entails integrating priority SD issues into teaching and learning. Unfortunately, ESD has not been thoroughly integrated into formal education curricula in Indonesian schools (Wulandari et al., 2018).

To improve a person's overall quality, having a significant amount of knowledge and the ability to think critically is crucial. ESD recognizes Critical Thinking as one of the competencies that helps develop this ability (Taimur & Sattar, 2019). While Critical Thinking Skills are undeniably crucial, studies worldwide suggest that students often demonstrate unsatisfying. According to some studies, the critical thinking skills of Indonesian students are placed in the low-level category of proficiency proficiency (Bustami et al., 2018; Purwati & Fatahillah, 2016). Another study assessing high-level cognitive questions of critical thinking among Junior High School students in Indonesia highlights a consistent bottom rank. Indonesia's performance in critical thinking skills based on the OECD remains concerning. It was ranked 64th out of 65 countries in 2012 (OECD, 2014) and 64th out of 72 countries in 2015 (OECD, 2017). These rankings demonstrate that Indonesia still lags in cognitive aspects such as knowing, applying, and reasoning (Kusuma *et al.*, 2017).

Besides the cognitive aspect, developing sustainable awareness is crucial for addressing SD challenges. Students can cultivate this awareness by gaining knowledge of necessary actions and avoiding harmful ones. This engagement helps them better understand environmental issues (Salsabila, Wijaya & Winarno, 2019). A study has found that though "sustainability (*keberlanjutan*)" has been introduced to university students through education, they may not fully comprehend the concept (Alsaati, El-Nakla & El-Nakla, 2020). Recent findings suggest that 70.1% of high

school students have a moderate level of awareness when it comes to environmental cleanliness, which they learned through environmental education (Devi & Lenin, 2018). The study on Sustainable awareness among Junior High School students in Riau Province produced satisfactory results. On the contrary, the implementation of sustainability practices in schools across the province falls short due to a lack of project activities that involve students (Ruslindawati et al., 2022). Based on those studies, it is apparent that the understanding of Sustainable awareness is incomplete and inadequately executed in projects that involve students.

Explorations into critical thinking and sustainable awareness have taken various forms, including examining student sustainable awareness through ESD integration, developing modules based on education for sustainable development on ecology concepts, and analyzing the critical thinking skills of students in science learning (Ekamilasari, Permanasari & Pursitasari, 2021). Nonetheless, current educational research lacks clear guidance for effective ESD lesson design (Riess et al., 2022). ESD aims to empower present and future generations with a balanced approach to economic, social, and environmental dimensions (Smith & Watson, 2016), allowing them to predict the future, identify problems, and make decisions collaboratively. Traditional teaching methods often limit critical thinking opportunities by promoting passive learning (Brown, 2003; Dole, Bloom & Kowalske, 2015).

Furthermore, integrating STEM (Science, Technology, Engineering, and Mathematics) learning is a pivotal strategy for addressing sustainability challenges (Smith and Watson, 2016). Integrating STEM and sustainability education is believed to create a population equipped to address issues for a sustainable society (Campbell & Speldewinde, 2022).

Based on the background, the study aims to investigate whether STEM ESD-based learning with "Arduino UNO-based Trash Can" improves students' critical thinking skills and sustainable awareness in learning about environmental pollution

METHOD

The pre-experimental design with one group pre-test-posttest has been conducted in this research. The participants were 36 7th-grade students in junior high school in Subang, West Java, Indonesia. The ten-item cognitive essay test was used to evaluate critical thinking skills. The assessment criteria for critical thinking skills were based on Facione (2015) (2015). It includes five indicators: interpretation, analysis,

inference, evaluation, and explanation. Then it was evaluated using a rubric scaling from zero to three.

The sustainable awareness was assessed using a Likert Scale questionnaire with four choices, ranging from 1= *sangat setuju* (strongly agree), 2 = *setuju* (agree), 3 = *tidak setuju* (disagree), to 4 = *sangat tidak setuju* (strongly disagree). The questionnaire comprised a total of 27 statements which evaluated three dimensions of sustainable awareness: The questionnaire measured three dimensions of sustainable knowledge, behavior, and attitude (Gericke et al., 2019.

The critical thinking skills and sustainable awareness instruments were subjected to thorough expert validation before being distributed to students in the pretest and posttest. Following this, reliability and validity were assessed using the Rasch Model with Ministep Winsteps software, considered the most accurate analysis method available.

Participants

The research was conducted at a public junior high school in Subang, West Java Province, during the academic period of 2023/2024. The target population for the study included seventh-grade junior high school students who had not formally learned the topic of environmental pollution. For this study, a sample size of 36 students was selected. The sampling technique was convenient sampling, a non-probabilistic method that selected the most easily accessible students within the school community (Creswell, 2018; McCombes, 2022).

Data Analysis

After three learning implementation meetings, the data from critical thinking skills and sustainable awareness were analyzed using the IBM SPSS version 25 statistical software package. The statistical analysis involved several tests, including the Normality test to determine if the data was normally distributed, the Hypothesis test to assess the research hypotheses, and the Normalized Gain to measure the learning intervention effectiveness.

RESULTS AND DISCUSSION

Students' Critical Thinking Skills

Critical thinking skills are valuable skills that enable individuals to think logically and rationally based on available information and evidence (Agbowuro & Keswet, 2016). The summarized results of the data analysis are presented in Table 1.

Table 1. Students' Critical Thinking Skills Statistical Summary

Data Type		Pretest	Posttest
N		36	36
Average Score		66.414	72.601
Standard Dev.		13.051	13.808
Normality Test (Shapiro-Wilk)	Significance	0.081	0.131
	Interpretation	Normally distributed	Normally distributed
Hypothesis Test (Paired T-Test)	Significance	0.004	
	Interpretation	There is a significant difference.	
Normalized Gain	Score	0.202	
	Interpretation	Low	

Based on Table 1, the results show a slight increase in the average score, but the critical thinking skills score achieved in both pretest and posttests remains good. The data distribution's pretest and posttest significance values are greater than 0.05 (> 0.05). It indicates that the data is normally distributed. Based on the normal distribution of the data, a Paired T-Test was performed to test the hypothesis. The test results suggest that the STEM ESD-based learning with the "Arduino UNO-based Trash Can" has improved students' critical thinking skills on environmental pollution.

The STEM ESD-based learning with the "Arduino UNO-Based Trash Can" offers students a valuable practical learning experience, successfully fostering enthusiasm. Since it's a hands-on activity, it allows students to engage in learning and develop their critical thinking skills actively. Through a hands-on activity, an appreciation and experience will be formed to establish an understanding (appreciation) because it can teach together psychomotor abilities (skills), understanding (knowledge), and affective (attitude) (Mubarok & Dwi Sulistyaningsih, 2020).

In addition, STEM education has the potential to engage students in active learning, foster collaboration among peers, and enhance their critical thinking abilities. According to a research study, incorporating STEM education can facilitate the development of conceptual understanding, creative thinking skills, and teamwork capabilities among students (Suardi, 2020).

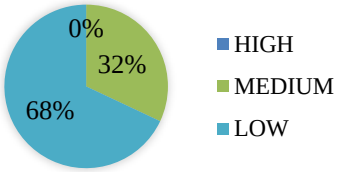

Figure 1 N-Gain Score Percentage of Students' Critical Thinking Skills

Based on the N-Gain score, it was found that the student's critical thinking skills showed minimal improvement. The

findings indicate that STEM ESD-based Learning with the "Arduino UNO-based Trash Can" is less effective in improving the students' critical thinking skills.

Among the 36 students, most are categorized as having a low improvement in critical thinking skills (Figure 1). The medium-level category is followed closely, and none of the students could attain a high level of improvement in critical thinking skills. There could be several reasons why the N-gain score was shown to be less effective. One possible reason is that the students did not have a strong foundation for enhancing critical thinking skills (Kania and Bonyah, 2023). It helps us recall and use what we have learned, reason, and acquire new knowledge. Time allocation was one of the pivotal factors that influenced the result. This is because the comprehensive and hands-on approach of STEM education requires significant time and effort to complete projects (Suripto *et al.*, 2023). Other factors, such as learning media and sources, also contributed to these results. This is in line with a study that found that the low development of critical thinking skills in learners was possible due to less supportive learning environments that do not emphasize critical thinking skills (Khairati et al., 2021).

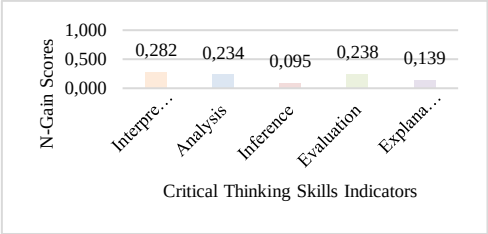

Figure 2 N-Gain Score Distribution of Students' Critical Thinking Skills

Figure 2 displays the distribution of students' N-Gain critical thinking skills indicators. All five indicators are categorized as low-level improvement (Hake, 1998). The learning intervention seems to be most effective in training the ability to interpret.

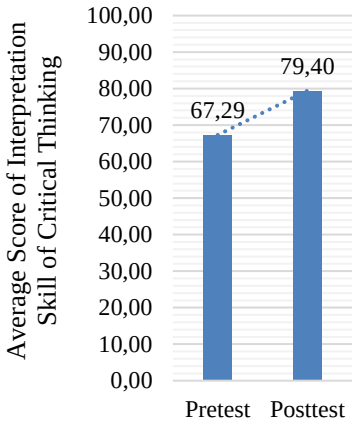

Figure 3 Students' Average Score Comparison of Interpretation Skill

Interpretation Skill in Students' Critical Thinking

The first indicator of critical thinking skills is the ability to interpret. This includes the sub-indicator of decoding significance (Facione, 2015).

According to the results of hypothesis testing, there was a significant difference between the pretest and posttest scores in Figure 3. This implies

that the STEM ESD-based learning with the "Arduino UNO-Based Trash CAN" improved the interpretation ability of critical thinking skills. The average pretest and posttest scores indicate an improvement in the average score after treatment. These results align with another research demonstrating that students have a very positive attitude toward critical thinking skills in interpreting information (Din, Hussain & Tahir, 2021).

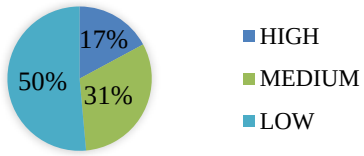

Figure 4 The N-Gain Score Percentage of Students' Interpretation Skill

Based on the distribution of N-Gain scores depicted in Figure 4, it was evident that the majority of students had a low category in the interpretation skill (Hake, 1998). Several factors, including the stages of STEM ESD-based learning in the ongoing learning process, could have influenced the outcomes; among them is the initial stage of problem formulation and design, creation, and redesign.

In the initial phase of the learning process, various activities are closely aligned with this indicator, specifically, the ability to interpret something. Among these activities is interpreting several pre-prepared images that illustrate various scenarios and actions closely linked to environmental pollution. In addition to enhancing students' interpretation skills, this introduction stage recalls their existing knowledge and prompts them to inquire with simple questions. Subsequently, in the initial problem formulation stage, students engage in activities centered on observing the school environment. The student's ability to interpret environmental conditions is essential in these tasks.

In the school observation activity, students must comprehend and articulate the significance of the environmental conditions present in their school. The data was then recorded in an observation table. The collected data was then carefully analyzed to identify potential problems or issues in the school environment. Even though they completed the observation table, the students' responses fell short of comprehensively describing the results.

The following stages are where students design, create, and redesign the "Arduino UNO-based Trash CAN" prototype. These three stages require critical thinking skills to comprehend and articulate the meaning of various forms of data or information. Students must understand the proposed solution or idea during the design stage by creating 2D prototype drawings. In the subsequent creation stage, students must

comprehend the procedures and design of the prototype and bring it to life as an actual trash can prototype. Lastly, during the redesign stage, students must identify the advantages and disadvantages of the product and interpret them as insights for upgrading it.

All groups were able to interpret the intended meaning quite well. However, more encouragement is needed to hone the ability until students can interpret information in the form they want. Active interaction between teachers and students and students with students was an essential factor in helping students improve this ability. However, not all group members were able to work well on this skill. Each individual has their limitations. This also causes the results in each group to be different.

As a result, the ability to interpret information indicates the most significant improvement. This improvement could be attributed to the high frequency of training in the learning stages. Regular engagement and repetition allow students to refine their interpretation skills and deepen their understanding of various forms of information. Evidence suggests that the ability to interpret data or images can be influenced by learning frequency. For instance, a study found that participants who were more frequently exposed to a specific type of image were better able to interpret and categorize those images than participants with less frequent exposure (Brady et al., 2008). Another study found that repeated exposure to a particular type of data visualization enhanced participants' ability to accurately interpret and use that visualization (Hullman & Diakopoulos, 2011). Overall, repeated exposure to a particular type of data or image can improve one's ability to interpret and categorize that information. However, the results may depend on factors such as the complexity of the information, the individual's prior knowledge and experience, and the specific learning methods used.

Analysis Skill in Students' Critical Thinking

Analysis skill involves analyzing and identifying both the intended and actual relationships among statements, questions, concepts, descriptions, or other forms of representation that convey beliefs, judgments, experiences, reasons, information, and opinions (Facione, 2015).

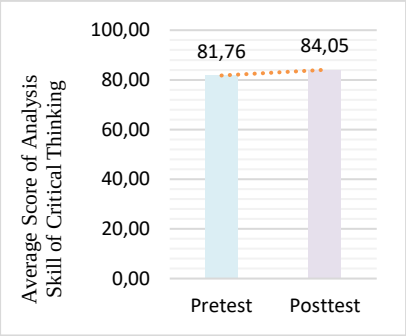

Figure 5 Students' Average Score Comparison of Analysis Skill

According to the available data in Figure 5, students' average score of analyzing abilities improved from the pretest to the posttest, although the increase was not considered significant. The average pretest score for the students was 81.76 and rose to 84.05 in the posttest. This suggests that they understood the content by examining the ideas presented. The rise in student performance could be linked to the activities at the beginning of the lesson. During that time, students were introduced to the topic being taught through a series of activities that provided them with the initial knowledge and contextual examples that made it easier for them to understand the subject matter. Some studies suggest contextual learning approaches can positively impact student achievement in various subjects and contexts (Kostøl & Remmen, 2022).

However, based on the hypothesis testing, the result was not satisfying. The Null hypothesis of analysis skill in critical thinking was retained. It was assumed that other factors can hinder or influence the improvement of student's ability in this indicator.

Moreover, the N-Gain score indicates that most students have a low level of comprehension in Figure 6. In other words, the learning was only very effective for 28% of the students (Facione, 2015). The stages of STEM subjects throughout the whole learning process could have impacted the results mentioned earlier. These factors might have played a crucial role in shaping the outcomes. Two stages included in the process were the Thinking stage, where ideas were generated and refined, and the Redesigning stage. In the Redesigning stage, students made improvements and modifications to existing designs.

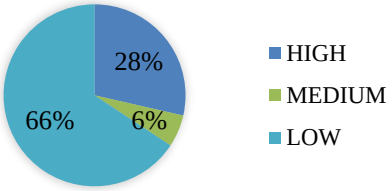

Figure 6 The N-Gain Score Percentage of Students' Analysis Skill

This stage assessed their ability to come up with solutions to the available problems. The worksheet demonstrated how well they could apply their critical thinking skills and creativity to generate effective solutions for the given scenarios.

All groups could analyze their problems well enough by linking some information, problems, judgment, and others to get a solution. An exchange of ideas occurred between students and also between students and teachers. Due to limited sources of information, the ideas they got were also limited. They only got it from their personal experience or their interaction with teachers and friends during discussions. This was one of the challenges in fostering this ability. As a result, students' ideas tend to be less varied and explorative.

Another example of embedding this analyzing indicator is shown in the testing and redesigning stage. Before the redesigning stage, students were trained to analyze and identify the advantages and disadvantages of the prototype they had created in the testing stage. For example, Group Blue stated that their prototype was not waterproof enough to resist the water. This understanding was used to improve their design, expressed in the 2D drawing of the prototype design. It was noticed that the student's responses were quite impressive in their simple way. Multiple factors can contribute to successful learning, and one of them is having productive interactions during the learning process. Students must comprehend the instructions and then do discussions that stimulate new ideas.

Based on the observation, the interaction that occurred among the students was found to be productive during the learning process. This was in line with a study on cooperative learning that found that productive interaction among students with different skills led to a better understanding of concepts and improved problem-solving abilities (Utaminingtyas, K. T., 2017). This way, they can develop their prototype way better. It should be noted that not all students faced this issue. However, some students struggled to develop appropriate ideas to enhance their prototypes, particularly when the Arduino UNO malfunctioned. As a result of limited knowledge and time, this section required additional guidance and instruction to ensure that students comprehended it thoroughly.

Inference Skill in Students' Critical Thinking

The third indicator of critical thinking skills is Inference Skills which focuses on conjecturing alternatives. This indicator helps draw reasonable conclusions by considering relevant information and exploring the consequences of different types of information (Facione, 2015). The goal is to form conjectures and hypotheses based on this information.

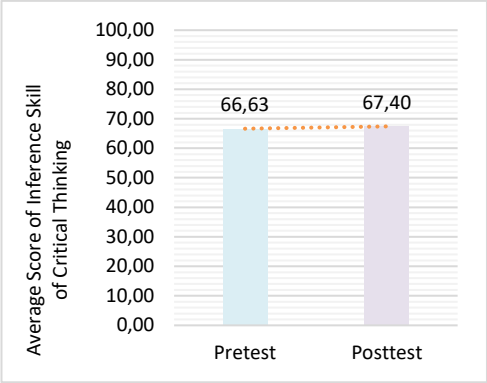

Figure 7 Students' Average Score Comparison of Inference Skill

The data presented in Figure 7 suggests a positive impact on students' performance. Although the increase may appear minor, the learning process positively impacted students' ability to draw inferences. It's worth highlighting that even a small improvement in scores could potentially lead to significant progress in overall learning and comprehension over time.

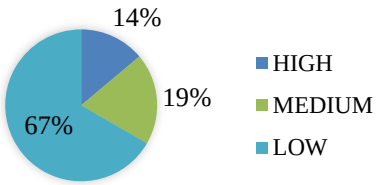

Figure 8 The N-Gain Score Percentage of Students' Inference Skill

Looking at the N-Gain distribution on this indicator (Figure 8), it's observed that the majority of students still have low scores. This means that the learning process aimed at improving inference ability in terms of conjecturing ideas has not significantly impacted most students. The remaining students, categorized as high and medium levels (Hake, 1998), have a similar distribution. These results were achieved by considering various factors during the learning process. One of the key factors is the redesigning stage, which focuses on enhancing the prototype design based on test results to produce an improved prototype. However, the outcome of the hypothesis testing was unsatisfactory. The null hypothesis regarding the Inference skill in critical thinking was accepted. Given the absence of a significant difference, it is presumed that other factors might impede or influence students' ability in this particular indicator.

During the testing stage, students tested their prototype and evaluated the advantages and disadvantages of the prototype they had created. Then student make an inference that, *"Sensor tidak bekerja dengan baik dan produk tidak tahan air"*. During the subsequent presentation, the group explained that:

"The sensor was not fully functioning as the lid was not fully opened and did not close automatically. We think that the cables and their connections may be the issue. Then, since many decorations were made from paper, they quickly became damaged if exposed to water. Then, the cables or electronic devices could malfunction if they come into contact with water. So, we need

solutions for this problem, and we will upgrade the prototype".

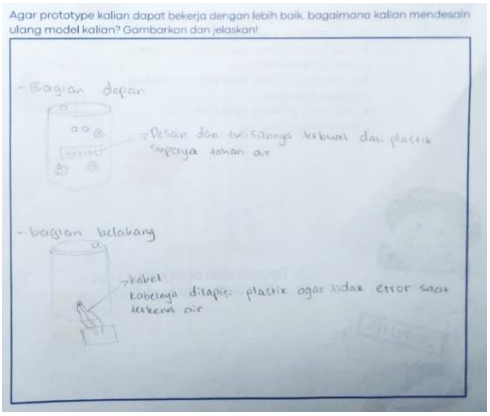

Figure 9 An alternative conjecture

In the next stage, redesigning the prototype, students were required to draw a prototype design addressing any deficiencies. Group Blue proposed the development of a prototype, as shown in Figure 9, as an alternative conjecture. This proposed development aimed to make the trash can more waterproof. However, not all groups performed well. Group Green and Red tend to copy each other. They seemed to be running out of ideas and hadn't fully grasped the information they had before.

Both at the testing and redesigning stages, first, students must understand the information that already exists before concluding something by coming up with innovations. In this research, the information referred to is information on the projects they carry out. Next, they have to understand the questions and relate them to each other. However, to create innovation, students also need creative abilities, critical thinking skills, communication skills, collaboration skills, and problem-solving skills (Herak, R. et al., 2019). Based on observation during the learning process, developing the skill of making inferences is quite challenging. Various internal and external factors could influence this difficulty. Individual characteristics, self-awareness, school education, and environmental factors all play a role in determining a student's willingness to innovate (Songwut, E., 2023).

Evaluation Skill in Students' Critical Thinking

Evaluation, which focuses on assessing the quality of arguments, is a part of critical thinking skills indicators. This indicator helps evaluate how well these statements and descriptions are logically connected to other statements, descriptions, and questions (Facione, 2015).

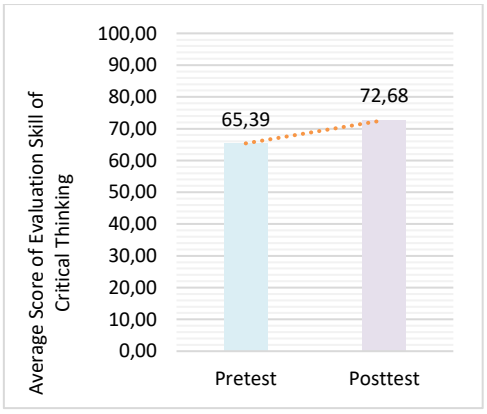

Figure 10 Students' Average Score Comparison of Evaluation Skill

According to the results of hypothesis testing, there was a significant difference between the pretest and posttest scores. After analyzing the information provided in Figure 10, it was

evident that the instruction positively impacted students' ability to evaluate the arguments' quality. Specifically, the average scores for the evaluation ability increased, which indicates a noteworthy improvement. This implies that STEM ESD-based learning with "Arduino UNO-based Trash Can" successfully improved students' ability to assess and analyze arguments, a crucial aspect of critical thinking and reasoning.

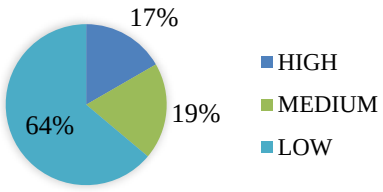

Figure 11 The N-Gain Score Percentage of Students' Evaluation Skill

The N-Gain percentage score for the evaluation ability (Figure 11) slightly differs from the previous indicator, classified as low-level (Hake, 1998). These results suggest that students could learn and use the skills and tools to assess arguments more effectively. This, in turn, helped them make more informed and well-reasoned judgments. Overall, the analysis confirms that the teaching successfully enhanced their ability to evaluate the quality of arguments. Moreover, the stages of STEM ESD-based learning have been emphasized significantly to provide a comprehensive understanding of the subject matter—for instance, problem formulation and thinking.

STEM learning can potentially improve students' ability to evaluate an argument by enhancing their critical thinking, problem-solving, and collaboration skills, which are essential for evaluating and constructing strong arguments (Yildirim and Turk, 2018). STEM-based learning has been found to influence the development of argumentation skills positively. By integrating STEM subjects into the learning process, students can apply their knowledge and skills to real-world problems, enhancing their ability to construct and present arguments (Fadhilah *et al.*, 2022). However, the effectiveness of STEM-based learning in improving argumentation skills may depend on the specific implementation and context of the learning experience.

The evaluation skill was present in different STEM Learning stages, forming a series. The problem formulation and thinking stages are crucial in building this skill because the entire series involves group discussions and the exchange of opinions. The series starts with identifying environmental problems in the school environment. This process leads to formulating a problem that needs to be addressed as a prototype. Next, students must conduct literature studies and discuss potential solutions related to

the problem. This stage results in a solution that can be realized in a prototype form.

In addition, during the learning process, students learn technical skills and how to assess the quality of arguments. Assessing the quality of an argument of others relates to interpersonal communication skills, which is essential for critical thinking as it allows individuals to examine their beliefs and attitudes in a new way (Moore, 2017). Interpersonal communication refers to sending and receiving messages between individuals or within a small group. It involves exchanging information, ideas, and feedback (Valentich, 1979; Banurea and Kuntoro, 2019). This skill is handy when they engage in group discussions during the presentation sessions.

Presentations were conducted multiple times throughout the learning process, during which students were expected to ask each other questions, provide suggestions, and offer constructive criticism. This process was intended to help them better understand the project at hand and develop new ideas to enhance it. However, this posed a challenge as many participants were in one class. In this situation, some students tend to be more confident and vice versa. More confident students tend to be more expressive in speaking and have many opinions.

Meanwhile, other students need more encouragement to speak up. Sometimes, the more active students also inhibit other students from speaking. Therefore, the right method is needed to guide students in discussions so that all students have sufficient opportunities to develop their abilities in class.

Explanation Skill in Students' Critical Thinking

The last indicator of critical thinking skills measured is explanation ability. This indicator focuses on the sub-indicator, namely, justifying procedure. This relates to clearly understanding a subject, and explaining its reasoning is important. This includes presenting evidence, concepts, methods, criteria, and context to support one's conclusions (Facione, 2015).

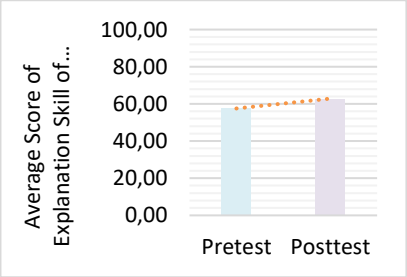

Figure 12 Students' Average Score Comparison of Explanation Skill

According to the hypothesis testing, the null hypothesis was accepted. It means that there is no significance difference in students' improvement.

However, based on the information presented in Figure 12, it can be observed that students' performance had been positively impacted. The data shows that the average scores for the ability to explain have increased, which indicates a noteworthy improvement. However, it is worth noting that the average scores for pretest and posttest were lower than those of other indicators. Nonetheless, the data suggests that there has been meaningful progress in the students' performance regarding their ability to explain.

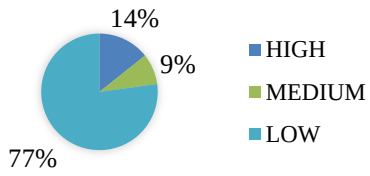

Figure 13 The N-Gain Score Percentage of Students' Explanation Skill

It was possible to infer that most students received low scores in explanation skills based on the statistical analysis of their N-Gain scores (Figure 13). This performance was similar to their results in other related indicators. This suggests that many students need additional support to improve their explanation skills. The data also indicates a significant gap between high-performing and low-performing students, so targeted interventions are necessary. Identifying the root causes of poor performance and providing personalized instruction and feedback can help students succeed academically and beyond. One of the factors that contributed to these results was the design stage, which was taken into account along with other factors. This stage involves matters related to the design of the "Arduino UNO-Based Trash Can" prototype, starting from the type and criteria of the trash can, tools and materials, and drawings of the prototype's shape.

During the design phase of the "Arduino UNO-Based Trash Can" prototype, the students had to develop a step-by-step procedure for creating the prototype. In this scenario, the students were expected to create a comprehensive procedure that met the specifications and requirements of the trash can, which served as a solution to the proposed problem statement. It appears that a considerable number of students struggle to create a well-structured, step-by-step procedure. Generally, students lack the knowledge and ability to write an accurate procedure for producing a product in paragraph or point form. Therefore, it was imperative to provide more detailed instructions and guidance on developing appropriate procedures based on the design they intend to create.

At first, they had to determine the type and criteria for the trash can. They needed to ensure that the criteria for the trash can were based on the type of trash can being made. At that stage, the

students seemed to be able to explain it thoroughly, indicating that they clearly understood the project's requirements. Although their writing steps were not comprehensive enough, they were still quite understandable. It was reported by the research findings that students who excel in the aspect of explanation are those who are capable of providing a thorough explanation of each step, procedure, and method utilized in problem-solving (Winarti et al., 2019). Besides, the rise in students' argumentation abilities correlates with their increase in knowledge (Mastuti et al., 2022).

Students' Sustainable Awareness

Sustainable awareness refers to personal sphere or self-awareness, which is essential in sustainability education. Self-awareness is a central sustainability competency that refers to the ability to recognize and understand one's own thoughts, feelings, and behaviors. It helps individuals understand their environmental and societal impact and make informed decisions promoting sustainability. The summarized results of these tests are presented in Table 2.

Table 2. Students' Sustainable Awareness Statistical Summary

Sustainable awareness (Questionnaire)		Pretest	Posttest
N		36	36
Average Score		3.026	3.124
Standard Dev.		0.338	0.298
Normality Test	Significance	0.350	0.906
(Shapiro Wilk)	Interpretation	Normally distributed	Normally distributed
Hypothesis Test (Paired	Significance	0.074	
T-Test)	Interpretation	There is no significant difference.	
Normalized Gain	Score	0.040	
	Interpretation	Low	

Table 2 presents that the average score of students on the pretest reflects their good level of agreement with statements on knowingness, attitudes, and behavior about environmental pollution. After receiving the treatment, the score slightly increased to 3.124, which is still at a level of agreement. These positive results suggest that the students had good sustainable awareness of environmental pollution. Both pretest and posttest significance values were above 0.05 (> 0.05), indicating that the data was normally distributed. The

outcome of the Paired T-test revealed that the null hypothesis (H_0) was accepted, indicating that there was no significant difference between the two paired samples being compared. Therefore, it can be inferred that even though students already have a sufficient level of sustainable awareness, the ESD STEM-based learning with the "Arduino UNO-based Trash Can" did not significantly improve students' sustainable awareness in learning about environmental pollution.

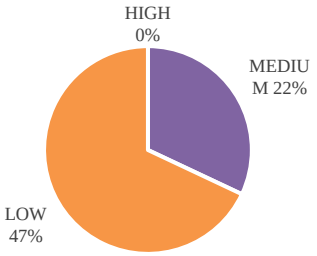

Figure 14 N-Gain Score Percentage of Students' Sustainable Awareness

Figure 14 shows that out of the 36 students, only those in the Low and Medium categories demonstrated improvement in their sustainable awareness. The majority of the students fall under the Low category. These findings suggest that none of the students were able to achieve a high level of improvement in Sustainable awareness (Hake, 1998). Several factors may influence the outcome, and one of them is likely to be a limitation on the amount of time allocated to the learning process. The time it takes for an individual to develop an awareness of sustainability may vary depending on their exposure to the concept and willingness to learn (Herremans & Reid, 2002). Raising awareness about sustainability is not a one-time event but a continuous process that requires a long-term commitment, including time and effort. It is important to note that consistent messaging and engagement are necessary for raising awareness effectively. The time it takes to raise awareness depends on factors such as the target audience, message, and medium used to convey the message.

The N-Gain score distribution of students' Sustainable awareness (Figure 15) was analyzed based on three indicators. The scores showed some variation between indicators, but unfortunately, all of the indicators had N-Gain scores lower than 0.3 (< 0.3), indicating a low level of improvement in the students' sustainable awareness (Hake, 1998). Despite this, the students' sustainable knowingness showed the most significant improvement due to the learning intervention. The following sub-section will provide a detailed explanation of each sustainable awareness indicator.

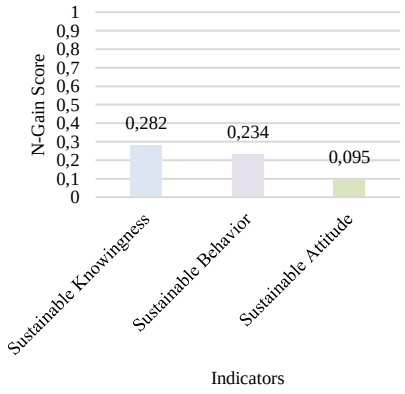

Figure 15 N-Gain Score Distribution of Students' Sustainable Awareness Indicators

Students' Sustainable Knowingness

Sustainable knowingness refers to understanding and recognizing sustainable practices and their impact on the environment, economy, and society (Gericke *et al.*, 2019).

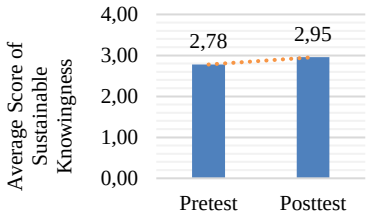

Figure 16 Students' Average Score Comparison of Sustainable Knowingness

After conducting a rigorous hypothesis test, it was found that the null hypothesis was rejected. This means that there was a statistically significant difference between the pretest and posttest scores. In other words, the ESD STEM-based learning program with "Arduino UNO-Based Trash CAN" positively improved the students' sustainable knowingness. In accordance with this result, the students' average scores from the pretest and posttest rose from 2.78 to 2.95 (Figure 16). Even with only a minor improvement, this positive result suggests that the learning intervention helped the students understand the impact of environmental pollution and how they can contribute towards sustainability.

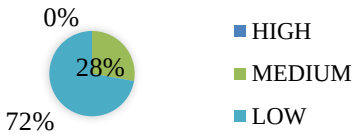

Figure 17 The N-Gain Score Percentage of Students' Sustainability Knowingness

The percentage distribution of N-Gain scores, as displayed in Figure 17, indicated that most of the students who participated in the intervention had a low-level improvement on sustainable knowingness (Hake, 1998). Nevertheless, at least 28% of the students had a medium level of improvement on sustainable knowingness, indicating some level of progress in their learning outcomes. On the other hand, the analysis did not reveal any students who had achieved a high level of improvement, indicating the need for further improvements in the intervention (Hake, 1998).

The findings reveal a concerning issue regarding the student's knowledge of environmental pollution in the context of sustainability. A previous study stated that students' knowledge of the

environment influences their ability to analyze and synthesize what happens to their environment (Prabawani *et al.*, 2020). This study promoted sustainable knowingness in the STEM learning stages: problem formulation and thinking. In the initial process of a problem formulating and observing their school environment, they were acknowledged about waste, waste management, and environmental pollution. The teacher did not provide direct explanations but instead provided contextual questions related to the concepts. Students were then asked to summarize what they had learned until they understood the subject well. This introductory phase is essential for their activity in observing the school environment as a base knowledge. This observation activity aimed to explored any problems in the school environment.

During the thinking stage, students conducted a literature review to explore possible solutions to the problems they identified in the previous stage. However, this phase presented a significant challenge as students were only allowed to use the school-provided textbook as their main source of information. The school neither provided technological devices nor allowed electronic devices or smartphones to assist students in their literature review. This limitation hindered the learning process as students could not explore knowledge or related information more deeply. To overcome this problem, the teacher took an active role in providing the necessary information. Additionally, since each meeting was held on a different day, students could conduct their research outside school hours. Unfortunately, the teacher did not provide clear technical instructions for the search tasks/homework, so many students ignored them.

In the design stage, students were required to construct their prototype design with environmentally friendly materials. However, students generally did not know what environmentally friendly materials were so they struggled in this stage.

All groups did not know the concept of environmentally friendly, so they could not answer the expected question. The red and blue groups answered but were unable to explain appropriately. Several studies revealed that having a strong knowledge base is pivotal in shaping behavior and attitude toward various objects or issues (Imamah et al., 2023; O'Bryhim, 2009). It helps form beliefs that form the foundation for individuals to take a stand and determine their behavior towards certain subjects. In fact, knowledge plays a significant role in shaping attitudes and beliefs,

which eventually influence behavior (Naslund & Fredrikson, 1993).

Students' Sustainable Behavior

Sustainable behavior involves the actions and practices that individuals adopt to promote and support sustainable living and the responsible use of resources (Gericke et al., 2019).

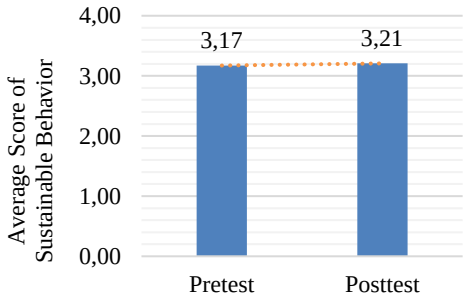

Figure 18 Students' Average Score Comparison of Sustainable Behavior

After conducting rigorous hypothesis testing, it was determined that the null hypothesis was accepted. No significant difference was found between the pretest and posttest scores. Hence, the ESD STEM-based learning program, which involved the "Arduino UNO-Based Trash CAN", did not improve the students' sustainable behavior. According to the data depicted in Figure 18, the average score of students before and after the tests showed only a slight improvement in the same agreement level.

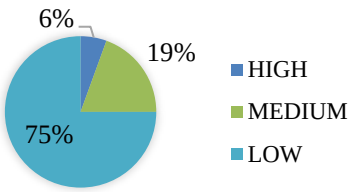

Figure 19 The N-Gain Score Percentage of Students' Sustainable Behavior

Based on the analysis of the percentage distribution of N-Gain scores presented in Figure 19, it was observed that the majority of students had scored low (Hake, 1998). This implies that most students did not effectively improve their Sustainable behavior after the learning intervention. However, the study revealed that only a small number of students were able to significantly improve their sustainable behavior and were classified as high (Hake, 1998). These findings suggest that the learning intervention was not as effective as desired in improving students' Sustainable behavior.

Numerous factors contribute to these outcomes, including adequate knowledge, consistent time and dedication, motivation, and various other potentials (Woodruff, Hasbrouck and Augustin, 2008; Kirby and Zwickle, 2021; Świecka *et al.*, 2021; Malt and Majid, 2023). Instilling sustainable awareness begins with students comprehending and acknowledging the importance of the environment. This was conducted in the very first stage, which is

the problem formulation stage. Consequently, a foundation of sustainability knowingness is a good basis, particularly in cultivating sustainable behavior (Malt & Majid, 2023).

In applying the STEM ESD-based learning with the "Arduino UNO-based Trash Can", information exchange becomes pivotal, involving inputs from educators, peers (students), and additional sources like the internet and books. However, challenges arise as students struggle to access desired information due to limited sources. Consequently, information exchange predominantly occurs through teacher and social interactions, posing a potential hindrance to establishing sustainable behavior.

Upon acknowledging the significance of environmental preservation, the subsequent phase involves transitioning behavior toward sustainability. Nonetheless, this transformation isn't instantaneous and proves challenging to attain. Cultivating sustainable behavior necessitates time and persistent dedication (Woodruff et al., 2008). Developing sustainable behavior is a challenging process that requires consistent repetition over an extended period despite being incorporated throughout the learning series. The limited duration of the learning process, which only spans three meetings, proved to be the biggest obstacle.

Subsequently, it's crucial for students to avoid bad habits. Avoiding bad habits such as littering and using materials that are not environmentally friendly can help reduce negative impacts on the environment. In practical application, students are acknowledged to avoid any bad habits that they can do in the class during the whole learning process, especially in the design and redesigning stages. After students can avoid bad habits, there should be habit transformation. Adapting sustainable practices, such as employing reusable shopping bags, selecting eco-friendly products, and opting for public transport or bicycles, significantly minimize environmental harm. Notably, habit transformation is not instant. It involves consistent and repetitive actions over time to establish better habits (Neal et al., 2006). Therefore, cultivating students in just three days was very challenging.

Finally, encouraging and inviting others to adopt sustainable behavior is a crucial aspect that needs attention. Such encouragement can speed up the process of sustainable behavior change. During the learning process, teachers can encourage students to adopt such behavior either by sharing stories or demonstrating examples of sustainable

behavior. The encouragement can start with basic things like putting waste in appropriate trash cans and reducing the use of plastic. For instance, plastic bottles can be replaced with reusable Tumblr bottles or plastic straws can be swapped with aluminum straws. Additionally, carrying reusable shopping bags (tote bags) can be helpful. Besides that, a study revealed that conversations about sustainability issues, particularly in a supportive and safe environment, can lead to stronger commitments and behavior (Kostøl & Remmen, 2022). However, only a few students were able to practice the skill during the second and third meetings, which suggests a potential correlation with student's motivation and desire to change their behavior.

In this case, poster-making was added to the learning activities. In a group, they were taught how to make a simple poster. Then they tried to share the poster through their social media to provide information and invitations to the audience.

Students' Sustainable Attitude

A sustainable attitude refers to an "enduring positive or negative feeling about some object, person, or issue" (Eagly & Chaiken, 1993; Kollmuss and Agyeman, 2002; Olson and Kendrick, 2008).

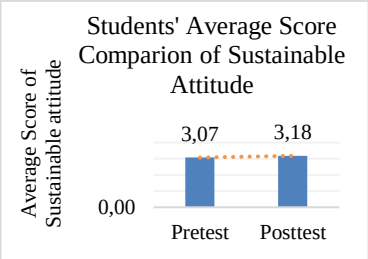

Figure 20 Students' Average Score Comparison of Sustainable Attitude

Upon careful examination and comparison of the data obtained from the pretest and posttest scores, it has been concluded that there was no statistically significant difference between the two. This implies that the null hypothesis was accepted. The results of this analysis suggest that the ESD STEM-based learning program, which entailed the "Arduino UNO-Based Trash CAN" did not significantly impact the test scores of the participants. According to the findings (Figure 20), there was only a minor improvement in the level of agreement between students' average pretest and posttest scores. Despite the progress made, the increase was not significant. Therefore, it is recommended that further research and intervention be conducted to achieve more substantial improvements in student performance.

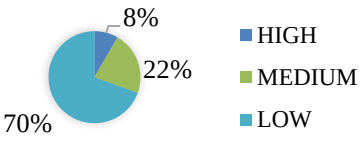

Figure 21 The N-Gain Score Percentage of Students' Sustainable Attitude

Based on the percentage distribution of N-Gain scores (Figure

21), it was found that a significant majority of the students had scored low (Hake, 1998). This indicates that most of the students did not effectively improve their Sustainable attitude after participating in the learning intervention. The findings further reveal that only a few students could significantly improve their sustainable attitude and were classified as High (Hake, 1998). Despite this, the percentage has a better result than sustainable behavior. These results suggest that the learning intervention was not as effective as expected in improving the sustainable attitude of the students.

Several factors can affect an individual's attitude toward environmental sustainability. These factors may include their knowledge of sustainability and interest in scientific issues (Wang et al., 2022; Riegel, 2023). Recent research studies have shown that knowing sustainability favors an individual's attitude toward sustainable development, including environmental, economic, social, and educational aspects (Uthama, Ahmad & Hassan, 2020; Ismail et al., 2022).

According to the results, knowing environmental pollution did not necessarily lead to positive, sustainable student attitudes. This was because each student is unique, and various factors could influence their attitudes. One such factor is their interest in scientific issues. Being interested in scientific issues can directly impact a person's nature-relatedness, which in turn can affect their sustainable attitudes and overall psychological well-being (Wang et al., 2022).

CONCLUSION

Several conclusions can be drawn from the analysis and it is described that the STEM ESD-based learning with "Arduino UNO-based Trash Can" improves students' critical thinking skills. The learning intervention generally holds a low-level category of effectiveness, which is only 20%. Interpretation is the most improved indicator of the five indicators of critical thinking skills (interpretation, analysis, inference, evaluation, and explanation), with an N-Gain Score of 0.282. Furthermore, the STEM ESD-based learning with "Arduino UNO-based Trash Can" did not significantly improve students' sustainable awareness of environmental pollution. However, from the three indicators of sustainable awareness (knowingness, behavior, and attitude), the students' sustainable knowingness showed the most significant improvement due to the learning intervention.

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