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ESD-STEM solid waste management project to enhance students' sustainability action in learning environmental pollution

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Abstract

Poor solid waste management can lead to significant environmental pollution, and the younger generation needs to be involved in finding solutions. The purpose of this study is to investigate the impact of involving students in ESD-STEM learning through solid waste management projects on improving engineering design skills and sustainability actions. A quasi-experimental design with a non-probability sampling method, especially convenience sampling, was used. There were two classes, one experimental and one control, each with 35 students. The instruments used included a validated and reliable sustainability action questionnaire. The questionnaire to measure changes in student actions was adapted from the Environmental Citizenship Questionnaire (ECQ) and ESD learning goals. The results showed a significant difference in the sustainability actions of students in the experimental and control classes after the learning process but with an increase in student action in the experimental class which was still low with an average N-gain score of 0.25. This shows that student involvement through the ESD-STEM solid waste management project has a significant influence on student sustainability actions, although the increase is still relatively low. These results prove that ESD-STEM learning is able to enhance students' sustainability action on environmental issues, but more optimal habituation and assistance are needed for more sustainable impact.

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Introduction

The amount of waste that isn't cleaned up pollutes the air, water, and land, and the harmful effects of the pollutants bring a significant health risk to people, animals, and plants (Debrah et al., 2021). Indonesia's current waste management system is facing some troubles in identifying the characteristics, amount, and type of municipal waste collected, primarily due to inadequate management and lack of human resources (Salsabila et al., 2021). About 56% of Indonesia's waste is taken care of by the government. The rest is burned (35%), buried (7.5%), composted (1.6%), or handled in some other way (15.9%) (Sari, 2016).

The sustainability of human life is significantly influenced by each individual's concern for environmental conditions and quality. All individuals must recognize that the balance of the ecosystem is essential for ensuring a livable and comfortable environmental condition (Fitriati, M., Sahputra, R., & Lestari, 2019). As stated in Sustainable Development Goal (SDG) number

12, which is Responsible Consumption and Production, emphasizes the importance of responsible consumption and production behaviors to maintain ecosystem balance and environmental quality. In education, promoting individual awareness of environmental responsibility among students from an early age is crucial for advancing the objectives of SDG 12.

Environmental awareness is crucial for influencing an individual's actions toward the environment. Students with better environmental awareness demonstrate more positive environmental attitudes (Li, 2018). Students with better environmental knowledge also demonstrate a more positive attitude toward environmental conservation (Azhar et al., 2016). However, students still have low environmental knowledge and awareness.

Previous studies have shown that students' level of knowledge and awareness about the environment is still low (Maresi & Basoeki, 2024). Another research done in one of the Central Java, Indonesia high schools reveals that students still lack environmental awareness and knowledge, which explains why they fail to act on the environment around them (A. Khoiri et al., 2021). Therefore, in order to improve students' actions in protecting the environment, it is necessary to enhance their environmental awareness and knowledge through education at the school level.

In science education, solid waste management is closely related to the material on environmental pollution that is taught. Junior high school students in grade 7 learn about environmental pollution, which is part of the Merdeka Curriculum in the ecology and biodiversity chapter. This environmental pollution topic highlights the need of learning about pollution in general, different kinds of pollution, what causes them, the effects they have on people and the planet, as well as mitigation and prevention efforts. However, research in one high school in West Nusa Tenggara, Indonesia, found that students' understanding of environmental pollution material is still lacking because they are passive, unable to relate the subject matter to the surrounding environment, and have difficulty in understanding the concepts that are presented theoretically (Awaluddin, 2025).

One way that schools can help raise students' environmental knowledge and awareness is by implementing the integration of Education for Sustainable Development (ESD) and Science, Technology, Engineering, and Mathematics (STEM). ESD gives students the information processing, decision-making, and action-oriented skills, beliefs, and attitudes they need to support social justice, economic sustainability, and the environment today and in the future (N. Khoiri et al., 2023). STEM seeks to enhance students' capacity for independent exploration as well as their ability to identify and solve problems using technology (Chang & Chen, 2022). As a result, the integration of ESD and STEM learning education has the potential to foster sustainable development practices (Yalçın, 2022). By introducing environmental issues through ESD STEM, students can engage so that they will be able to think critically and systematically to solve those environmental issues.

ESD has often been used to raise awareness of sustainable development, especially when it comes to environmental issues like solid waste management. However, Debrah et al. (2021) examine the role of formal education in enhancing awareness of solid waste management; however, they do not address the use of Education for Sustainable Development (ESD) in STEM education to promote sustainable waste practices. One of the factors that might affect

the implementation of ESD-STEM in Indonesia is that it has not been widely implemented in the classroom because not many teachers have a background in STEM learning for sustainability (Zuhaida et al., 2024).

Furthermore, the solid waste management project is the alternative project that can be done in ESD-STEM learning process. Previous study states that doing a projcent in learning process foster students' environmental awareness (Wibowo et al., 2024). The common thing that happens as the problem of solid waste management is that people still do not care about their solid waste production. In fact, solid waste arises as a result of people's activities towards their environment in fulfilling their needs (Kartomiharjo et al., 2019). Previous research indicates that an effective method for managing solid waste to mitigate environmental issues involves the separation of solid waste into organic and inorganic categories for the following application (Puriana et al., 2021). Therefore, in this project, students will be given the opportunity to create a solution for better solid waste management, such as the waste sorting process.

Based on the following explanation, this study aims to investigate the improvement of students' sustainability action through the ESD-STEM solid waste management project in learning environmental pollution. The results of this study are expected to help in improving students' sustainability actions as students are given the opportunity to contribute to solid waste management that they often encounter by participating in the project, so that they can gain new experiences through the ESD-STEM learning. Also, this ESD-STEM project can be used by the teachers as an idea for learning activities to enhance students' sustainability action.

Method

The method of this research was a quasi-experiment by using the pretest-posttest non-equivalent control group design. There were two groups that were observed in this study, which were the experimental group that studied with ESD-STEM learning on a solid waste management project, while the control group studied with the steps of conventional learning that is usually carried out by teachers. The population in this study was 7th-grade students in Bandung public school who used the Merdeka Curriculum with the total number of students both in experimental and control class were 35. This research used the non-probability sampling technique, which is convenience sampling, because the sampling was conducted by the school due to the availability and classes that were considered to have the same basic knowledge about environmental pollution issues.

The sustainability actions of the students were assessed through the development of the Environmental Citizenship Questionnaire (ECQ) from Hadjichambis & Paraskeva-Hadjichambi (2020). The questionnaire consists of 52 items, with 27 items for past, present, future actions and 25 items for the competencies. The score used is a 4-point Likert scale with a maximum point is 4 and a minimum point is 1. Students choosed the options that reflect their daily habits related to the environment and the level to which they feel capable of taking sustainable action. For the past and present action indicator, the 4 options are never, rarely, often, and always, while for future action, the options are will not do, hesitate to do, try to do, and sure will do. For competence, the options consist of very incapable, incapable, capable, and very capable. The questionnaire was distributed to the students at the beginning of learning (pre-test) and at the end of learning (post-test) for both experiment and control class.

The topic in the questionnaire are based on the ESD learning goals for SDG 12 as one of the sustainable development goals relevant to the issue of solid waste management, namely Responsible Consumption and Production which emphasizes changes in consumption and production patterns to be more environmentally responsible. The ESD learning goals with three domains include cognitive, socio-emotional, and behavioural are analyzed and applied to ESD-STEM learning on solid waste management to create relevant and quantitative indicators of students' sustainability actions.

The experimental class conducted ESD-STEM learning through a solid waste management project, whereas the control class will learn through teacher's regular model. Because of the different model used, the time taken was quite different. The experimental class took about six meetings, with two meetings at home, while the control class took only 4 days without any tasks at home. The data collected from students were analyzed qualitatively and quantitatively. The qualitative data were collected through the interviews with selected students while the quantitative data were collected from questionnaire given to students at the beginning and at the end of the learning activity. The data analysis began with normality, homogeneity, and hypothesis tests to facilitate for further analysis and then the average pre-test and post-test scores of students' sustainability actions were compared between the experimental and control groups. The scores on the pretest and posttest demonstrate the impact of ESD-STEM learning as determined by statistical calculations with the results of the pretest represents the initial actions taken by students before the learning activites and postest represents the actions taken after the learning activities. The explanation of the results begins with the meaning of the data that has been statistically processed using the independent t-test, followed by the results of ESD-STEM learning during product development. Then, an SPSS analysis of students' sustainability actions is presented, with each indicator explained in detail.

Results and Discussion

The results of the analysis of students' sustainability actions show that the average for students in the experimental class is 2.89, while the average for students in the control class is 2.90. These results show that the initial ability of students in the experimental and control classes was relatively the same. Moreover, the results of the hypothesis test show that there is no significant difference between the experimental and control classes before the implementation of ESD-STEM learning (p-value (0.874) > α (0.05)). This could have happened because the integration of SDGs goals in the learning process is still limited, even though the independent curriculum encourages contextual and project-based learning that shows a connection to ESD values (Anisa Sari et al., 2022). The results of this pre-test show that students in both experimental and control classes have a lack of understanding of sustainability. The results of the data analysis can be seen in table 1.

In this study, students in the experimental and control classes were both asked to make a product to overcome environmental pollution, especially due to solid waste problems. Although both have the same output, which is the product, there are differences in the learning process. Learning in the control class was carried out by applying the usual method used by teachers or conventional learning, while the experimental class used ESD-STEM learning. After being involved in the ESD-STEM solid waste management project, the average of the experimental

class increased by 0.29 to 3.18 and experienced a greater increase compared to the control class, which only increased by 0.10 to 3.00. This result shows a significant difference between the means of the experimental and control classes, which is also evidenced through the results of the hypothesis test, which shows a significant difference between the experimental and control classes after the learning is carried out (p-value (0.029) < α (0.05)). This shows that there is an effect on students' sustainability action through students' involvement in the ESD-STEM solid waste management project.

Table 1. The Results of The Data Analysis

Analysis Component	Experimental Class	Control Class	Statistical Result	Interpretation
Pretest Mean	2.89	2.90	p-value = **0.874**	No significant difference before learning; both classes have similar initial understanding of sustainability
Posttest Mean	3.18	3.00	p-value = **0.029**	Significant difference between groups after learning ($p < 0.05$)
Mean Increase (Post – Pre)	+0.29	+0.10		Experimental class shows greater improvement after ESD-STEM project
Average N-Gain (Experimental)	0.284	0.10		
N-Gain categories	Moderate = 58.1%	Low = 41.9%		

In the control class, conventional learning was conducted by starting with a picture of a dirty neighborhood as an example of the impact of environmental pollution. Although this picture could stimulate discussion, the context was general and not directly related to what the students experienced. The results showed that learning in the control class did not have a big impact on increasing students' sustainability actions. The changes that occur tend to be minimal, so they are not enough to encourage students to form a real sustainable understanding and actions in everyday life. On the other hand, in the experimental class, learning activities began with direct environmental observations conducted in groups. This activity aims to encourage students to identify environmental problems, especially due to solid waste. By interacting directly with the environment during the learning process, like by observing the environment to see what problems are happening, students become more involved and not only gain a better

understanding, but they can also develop an awareness of and concerns about the environment (Chrislando, 2019).

Environmental awareness involves recognizing the mutual relationship between humans and the environment, as well as an awareness of our responsibility to act in a sustainable manner to maintain the sustainability of the environment for future generations (Miterianifa & Mawarni, 2024). Hence, students in the control class did not have the opportunity to explore the problems that occurred around them directly.

When conducting environmental observations, students are not only able to identify existing problems, but they are also encouraged to be more empathetic to their surroundings. Experts describe empathy as an important factor for getting the feeling of confidence in their ability to make changes that have a positive and sustainable impact globally (Helmi & Herliani, 2021). ESD-STEM also encourages students to act consciously and be responsible towards their social environment. ESD seeks to support learners through the development of competencies for sustainability problem-solving and enable them to participate in sustainable development while critically reflecting on their own actions (Fischer et al., 2022). As a result, through ESD-STEM, students are given the opportunity to make real changes even on a small scale, but strengthen their ability to act and make decisions (Pahnke et al., 2019).

However, from the results of the N-gain analysis in the experimental class, the average result shows that the increase in student action in the experimental class is still relatively low, at 0.25 and further N-Gain calculations were carried out to determine the increase in action for each student, with the results showing that 58.1% of students showed an increase in action in the moderate category and the remaining 41.9% were in the low category.

Table 2. N-Gain Analysis of Students' Sustainability Actions in the Experimental Class

Analysis Component	Result	Description
Average N-Gain	0.25	Overall increase in students' sustainability actions is categorized as low
N-Gain Category Distribution	-	-
Moderate Category	58.1%	More than half of the students experienced a moderate increase in action
Low Category	41.9%	Nearly half of the students experienced a low increase in action
High Category	0%	No students reached the high category of improvement
Conclusion		Students' sustainability action increased after ESD-STEM learning, but overall increase remains low to moderate

This shows that although ESD-STEM learning focuses on taking action to address a real-world problem, not all students respond with a high level of action change. The lack of increased action occurs due to a lack of awareness to understand the impact of actions taken on the

environment, which was also stated by students in the experimental class that according to them many people still carry out actions that may pollute the environment because there is a feeling of laziness to understand the big impact on the environment. (Representative of group 2)
Lack of environmental knowledge causes students to lack information that is the basis for behavior that does damage the environment (Munawar et al., 2019). Students' awareness of the environment can lead to responsible environmental attitudes and behaviors in maintaining and preserving the environment (Azrai, E. P., Sigit, D. V., & Puji, M., 2018).

The low influence of learning on improving sustainability actions can also be related to the limited implementation of ESD in Indonesia. The success of implementing ESD into school learning and practice highly depends on how competent and committed teachers are in terms of sustainability (Barth, 2014). Many educators face difficulties in understanding and integrating SDGs concepts in daily learning due to lack of training and mentoring, restricting the effective implementation of Merdeka Curriculum to teach sustainability values (Anisa Sari et al., 2022). Moreover, ESD has not been widely implemented in Indonesian education, especially in science (Vilmala et al., 2022). Therefore, limitations in the understanding and application of ESD as a whole contribute to the low effectiveness of learning in promoting changes in students' sustainability actions.

Past, present, and future actions

The first indicator sustainability action is about action, which is divided into 3 periods, namely past, present, and future. Changes in the actions of each student in the experimental and control classes, ranging from past, present, and future actions, can be seen in the figures below.

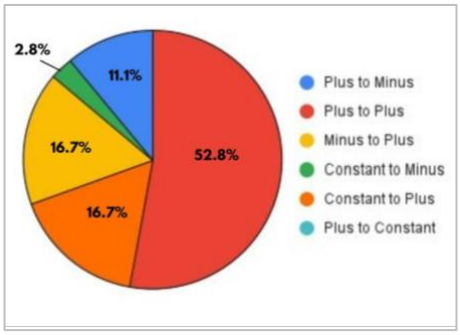


Figure 1. Results of Changes in Action per Individual Student in Experimental Class

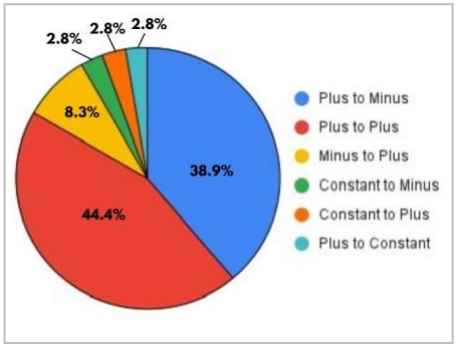


Figure 2. Results of Changes in Action per Individual Student in Control Class

The changes shown indicate the number of changes in each student's action over time based on the action indicators of past, present, and future. From the diagram, the categories in the experimental and control classes are almost the same, with a total of 6 categories, all of which are in the experimental class.

In both the experimental and control classes, the category with the largest number is Plus to Plus, which shows that there is always an increase over time, with a total of 44.4% in the experimental class and 52.8% in the control class. As the Plus to Plus category is dominant in these two classes, students in both the experimental and control groups are very motivated to take action against environmental pollution, especially the waste problem. This could have happened because in the experimental class and control class, students were making the product by themselves to help in overcoming solid waste issues. Through the involvement in the project, it will likely encourage students' desire to take action. One of the ways to foster students' environmental awareness through the learning process is by doing a project (Wibowo et al., 2024). This awareness plays an important role in fostering internal motivation and a sense of responsibility in students to take real action in protecting the environment, this is in line with the results of student interviews which stated that the project learning carried out really helped them in realizing the importance of protecting the environment and how to manage waste properly, so that they are increasingly motivated to act better. (Representative of group 1)

The second is the Minus to Plus category, which shows that there is a decrease from the past to the present but there is an increase from the present to the future, with the experimental class has a percentage of 8.3%. This difference in change from the past to the present and from the present to the future can happen because of this ESD-STEM learning. After the ESD-STEM solid waste management project, they were more motivated to take action to protect the environment. This aligns with students' statements, stating that "After participating in the lesson, they have become accustomed to sorting waste according to type and reminding their friends to dispose of waste properly and according to type. (Representative of group 5)

However, the control class has a bigger percentage of 16.7% which indicates a change in action for the better for the future for the control class students. This can happen because students who experience meaningful learning tend to evaluate themselves more realistically and not overstate their future expectations. Thus, although the experimental class received STEM-ESD-based learning designed to increase motivation, care, and sustainable action, the average change in action from the present to the future was better in the control class, which is also shown from the Plus to Minus category results. The experimental class got a higher percentage at 38.9% while the control class was only 11.1%. As stated by Wals (2014), ESD plays a role not only in building optimism but also in forming critical awareness that is essential for sustainable action. Thus, the results of this category can be interpreted as a form of realistic reflection from experimental class students who have experienced ESD-STEM learning. They become more critical and aware that environmental action requires sustained and collaborative efforts, so they tend to carefully assess their future. In contrast, students in the control class who received conventional learning tended to respond optimistically because they were not confronted with the complexity of real-world problems. This also aligns with students' statements that they are now more likely to think before acting, such as reducing plastic use

because they are aware of its significant impact on the environment. (Representative of group 3).

Furthermore, Constant to Plus category which indicates that there is an increase from past to present, but has the same score in the present and future also found more in the control class with a percentage of 16.7% while in the experimental class only 8.7% which could occur due to the critical awareness of students in the experimental class because of the ESD-STEM learning.

In experimental class, another 2.8% for the last two categories are Constant to Minus and Plus to Constant. The Constant to Minus shows that students have the same score for past and present actions, but a decrease in future actions. For this category, the experimental class and the control class got the same percentage. Students in this category tend to be more passive in the future, which can be caused by the difficulties felt by students in taking action to protect the environment. The difficulties students experience in carrying out an activity are usually due to environmental factors, such as family, which is their closest environment. This also aligns with students' statements that they encounter several difficulties, such as sorting waste, because they are not accustomed to sorting waste at home. (Representative of group 1)

The last category, Plus to Constant category, indicates that there is an increase from past to present, but has the same score in the present to future, which only appears in the experimental class' data. This category indicates that positive changes in the present do not alter future action plans. Students justify their continued actions by stating that they remain unchanged because they have become habits and their impact is not immediately noticeable. (Representative of group 3)

Furthermore, statistical calculations were used to look at the students' actions toward sustainability before and after the ESD-STEM learning process. Statistical calculations are divided down into a total of three actions taken in the past, actions taken in the present, and actions that will be taken in the future. The first is about the past action with the students' average score is shown in the figure below.

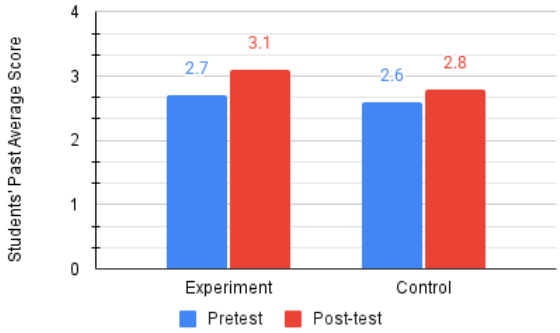


Figure 3. The Average Score of the Students' Sustainability Action for the Past Action

Both experimental and control classes experienced an average increase, with a greater average increase of 0.4 in the experimental class, while the control class experienced an average increase of only 0.2. The difference in the increase experienced by these two classes is not too contrasting but still shows a better average increase in the experimental class.

Past actions for sustainability refer to the actions taken by students to address environmental concerns in the past (Hadjichambis & Paraskeva-Hadjichambi, 2020). It means that past actions are experiences that have already happened and cannot be changed. However, the increase in the average score indicates that students are reflecting on their past actions. A previous study has shown that when students reflect, they start to question their thoughts and actions. It makes them more willing to reflect on past bad habits and more ready to change their actions (Kemper, 2021). As a result, in ESD, this experience and critical reflection on personal experience are one of the essential processes (UNESCO, 2017). This encourages students to reevaluate their past habits, assess their impact, and begin to assess whether their actions are appropriate. This is reinforced by students' statements that their current actions are not entirely sufficient, but they will try to start small and commit to continuously improving their habits. (Representative of group 1)

This statement reflects a self-evaluation of past actions, including any possible shortcomings or inconsistencies in environmental protection. Such reflection is a crucial stepping stone in shaping future action and behavior.

The second is about the present action for sustainability. The average score of the students' sustainability action for the present action is shown in the figure below.

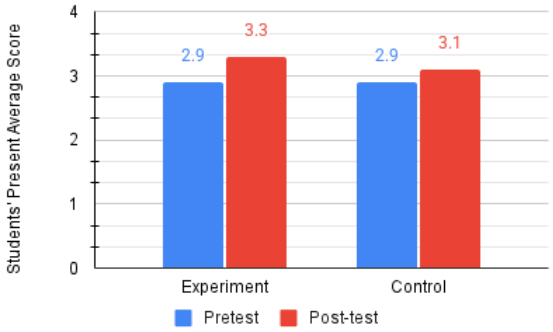


Figure 4. The Average Score of the Students' Sustainability Action for the Present Action

Both experimental and control classes experienced an average increase, with a greater average increase experienced by the experimental class of 0.3, while the control class was only 0.2. The difference in the increase experienced by these two classes is not substantial, but still shows a better average increase in the experimental class, with a difference of 0.1. When analyzed using gain (difference in score increase), the 0.3 difference in increase between the experimental class and the control class of 0.2 cannot be directly considered significant based on the numerical value alone. To determine significance, each student's gain value must be statistically tested using an Independent Samples t-test for gain scores.

Present actions for sustainability are the actions taken by students to address environmental concerns in the present (Hadjichambis & Paraskeva-Hadjichambi, 2020). This suggests that present actions can change, but within a fairly short timeframe. The thing that distinguishes between present and future actions is that present actions are related to the behavior that students exhibit during learning or shortly after the learning process is completed, while future actions have not yet occurred and are limited to intentions or plans. Therefore, based on the

results of the average increase. ESD-STEM learning implemented in experimental classes influences students' current actions. This is in line with what was experienced by one of the students who stated that after participating in the learning, he had developed a new habit, namely starting to get used to sorting waste. (Representative of group 5). This statement shows that students not only understand that waste is harmful to the environment, but they are also taking concrete steps to address it.

Through the ESD-STEM solid waste management project, students are encouraged to be more aware and concerned about their surroundings. Studies have shown that STEM learning provides students with opportunities to learn more about and care more deeply about environmental problems (Owojori et al., 2022). Thus, students not only understand the importance of protecting the environment, but they also immediately start taking action, which is reflected in real behavioral changes, such as sorting waste. Additionally, this aligns with an earlier study that found STEM-based learning models have a significant impact on students' environmental awareness (Rahmadayanti et al., 2025).

The last in this indicator is future action. Future actions refer to the steps students will take in the future to address environmental issues both inside and outside school, and to act as agents of change (Hadjichambis & Paraskeva-Hadjichambi, 2020). The average score of students' sustainability action for future action is shown in the figure below.

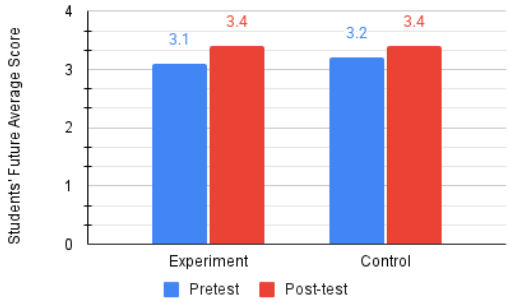


Figure 5. The Average Score of the Students' Sustainability Action for the Future Action

From the result, both experimental and control classes experienced an average increase, with a greater average increase of 0.4 in the experimental class, while the control class experienced an average increase of only 0.1. The difference in the increase experienced by these two classes is not too different, but still shows a slightly better average increase in the experimental class. The difference in average improvement between the experimental class (0.4) and the control class (0.1) cannot be considered significant based on the numerical difference alone. To determine whether the improvement is statistically significant, the scores of all students must be analyzed using an Independent Samples t-test. The improvement can only be categorized as significant if the resulting p-value is below 0.05.

Future actions relate to intentions or plans that students have not yet implemented. Consequently, the future action indicator reflects the extent of students' determination to change, as evidenced by their post-learning reflections, which indicated they were more confident about future changes because they began to realize the importance of environmental stewardship, particularly regarding waste management. (Representative of group 1). This

statement demonstrates that learning has made students more self-aware and instilled in them a desire to change for the better, which is what long-term, sustainable action is all about. Having the desire to change is an important first step in education for sustainable development, because it's hard to change behavior when individuals don't want to consistently.

As agents of change, students must have strong motivation and commitment to carry out the plans they have. According to an Indonesian education expert, youth is defined as a generation in the process of forming its personality and character, and they are expected to possess a spirit of learning, creativity, and make positive contributions to society (Atikoh et al., 2024). Furthermore, in support of SDGs 12, the ESD-STEM was implemented in an experimental class. Students can become agents of change through a learning system that integrates Science, Technology, Engineering, and Mathematics (STEM) (Setiawan et al., 2020). Through ESD-STEM learning, students develop their environmental awareness by creating a product as a solution to overcome environmental problems. The ESD-STEM solid waste management project was also carried out both indoors and outdoors, providing students with varied learning experiences and more opportunities to explore.

The outcome of the project extends beyond the product, and it is also shared with the community through social media. One of the efforts that students can undertake as agents of change is to develop action strategies, such as socialization through the media, to increase awareness and promote sustainable waste management (Ghafur & Alviansyah, 2025). Moreover, it also stated that students can maximize their attention to a socio-environmental problem through proper networking on local, national, and global networks. It ultimately plays a critical role as agents of change for the environment and sustainability (Hadjichambis & Paraskeva-Hadjichambi, 2020). As a result, this activity demonstrates that students in the experimental class are not merely passive learners. Still, they are learning to carry out their role as agents of environmental change.

Competencies

The second indicator in this variable is the achievement of student competence. Competence encompasses students' knowledge, conceptions, skills, attitudes, and values in dealing with environmental issues and overcoming them (Hadjichambis & Paraskeva-Hadjichambi, 2020). For this indicator, data is obtained from the competency action questionnaire given to students. This competency action questionnaire contains 25 items, each using a 4-point Likert scale, and each item will be assigned a score. The average of the pre-test and post-test scores for this competency indicator is shown in the figure below.

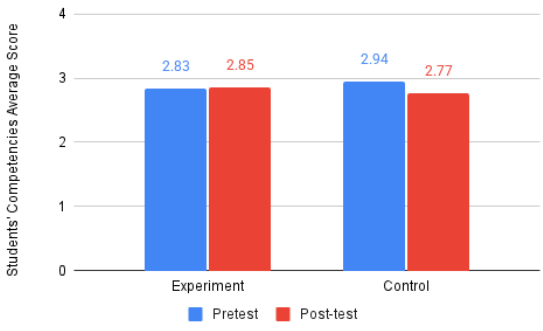


Figure 6. The Average Score of the Students' Competencies of Sustainability Action

The results of the questionnaire showed different results between the pretest and post-test in the experimental and control classes. The experimental class demonstrated an increase in competency achievement from the pretest to the post-test, whereas the control class showed a decrease in this competency achievement. The experimental class showed a 0.02-point increase from the pretest to the posttest. Therefore, although the difference in improvement was not substantial, the results in the experimental class demonstrated that the ESD-STEM solid waste management project supported the development of students' competencies in a more meaningful and sustainable manner. Improvements in learning outcomes—no matter how small require statistical verification to determine whether an instructional intervention (such as an ESD-STEM project) actually produces a meaningful effect. Thus, improvements can only be considered significant if supported by a corresponding p-value below 0.05.

ESD-STEM explicitly supports the achievement of the SDGs by equipping learners with interdisciplinary skills and knowledge needed to address global challenges (Sihombing et al., 2024). By analyzing important concepts in the real world, students understand the cause-and-effect relationships in environmental issues, particularly in terms of their social, economic, and environmental aspects, which helps shape students' conceptions and knowledge. The process of observation, discussion, reflection, and socialization also encouraged students to realize that their small actions can have a broader impact. Furthermore, students in the experimental class began to feel motivated to do better. As expressed by a student in an interview, who stated that the learning that has been done has really helped me realize the importance of protecting the environment and how to manage waste properly, so that I am increasingly motivated to act better. (Representative of group 1)

The following statement suggests that students not only learn knowledge and skills, but also change their beliefs and values. For example, they become more aware of the need to protect the environment through real-life learning situations.

Aligns with the statement that these competencies must be developed by students themselves, acquired through action, experience, and reflection (UNESCO, 2017). Students not only learn about the subject through discussion and reflection, but they also develop important values, such as being open, honest, and logical when presenting their results. These values help students develop action skills that are not only based on knowledge, but also moral awareness and environmental responsibility (National Research Council, 2012). As a result, the experience that students gain from this ESD-STEM learning process helps them develop their action competencies.

Conclusion

Based on the result and discussion, the implementation of the ESD-STEM solid waste management project has had an impact on students' sustainability actions which is evidenced through the results of the hypothesis test that shows a significant difference between the experimental class and the control class after learning (p-value (0.029) < α (0.05)). The results also showed a significant difference in the sustainability actions of students in the experimental and control classes after the learning process but with an increase in student action in the

experimental class which was still low with an average N-gain score of 0.25. This shows that student involvement through the ESD-STEM solid waste management project has a significant influence on student sustainability actions, although the increase is still relatively low. These results prove that ESD-STEM learning is able to enhance students' sustainability action on environmental issues, but more optimal habituation and assistance are needed for more sustainable impact. Nevertheless, these results suggest that the implementation of the ESD-STEM solid waste management project has led to increased student engagement in sustainability actions. Through the ESD-STEM solid waste management project, students can develop awareness, motivation, and a positive intention to make changes. These results are influenced by several factors, including students' knowledge, awareness, and the environment surrounding them. To support the improvement of more meaningful sustainability actions among students, the learning experience should provide more opportunities for students to explore ideas through discussion with peers, with the teacher, or by drawing on literature with more effective guidance.

Credit Authorship Contribution Statement

Fildzah Nabiila Rabbani: Conceptualization, Methodology, Data curation, Formal analysis, Visualization, Writing – original draft, Writing – review & editing. **Ari Widodo:** Conceptualization, Methodology, Supervision, Validation. **Eliyawati:** Methodology, Resources, Supervision, Project administration.

References

Ahel, O., & Schirmer, M. (2022). Education for sustainable development through research-based learning in an online environment. *International Journal of Sustainability in Higher Education*, *24*(1), 118–140. https://doi.org/10.1108/IJSHE-07-2021-0305

Anisa Sari, G. M., Antika, V. Y., Wisutama, R. A., Syiami, L. N., Sulaeman, N. F., Nuryadin, A., & Subagiyo, L. (2022). New Indonesian Science Curriculum for Junior High School: A Content Analysis to Support STEM SDGs. *Jurnal Literasi Pendidikan Fisika (JLPF)*, *3*(2), 176–182. https://doi.org/10.30872/jlpf.v3i2.1555

Atikoh, N., Suci, N. R., Mubarok, M. R., & Fuad, M. Y. N. (2024). The Role of Youth as Agents of Change in Realizing Sustainable Development Goals: A Humanistic Theory Perspective. *Proceeding of International Conference of Religion, Health, Education, Science and Technology*, *1*(1), 415–419. https://doi.org/10.35316/icorhestech.v1i1.5668

Awaluddin, R. (2025). Penerapan Model Problem Based Learning (PBL) Berbasis Kearifan Lokal pada Materi Pencemaran Lingkungan Untuk Meningkatkan Pemahaman Siswa Kelas X di SMAN 2 Bolo. *Jurnal Jendela Pendidikan*, *5*(02), 312–321. https://doi.org/10.57008/jjp.v5i02.1340

Azhar, A., Basyir, M. D., & Alfitri, A. (2016). Hubungan Pengetahuan Dan Etika Lingkungan Dengan Sikap Dan Perilaku Menjaga Kelestarian Lingkungan. *Jurnal Ilmu Lingkungan*, *13*(1), 36. https://doi.org/10.14710/jil.13.1.36-41

Chang, C. C., & Chen, Y. (2022). Using mastery learning theory to develop task-centered hands-on STEM learning of Arduino-based educational robotics: psychomotor

performance and perception by a convergent parallel mixed method. *Interactive Learning Environments*, *30*(9), 1677–1692. https://doi.org/10.1080/10494820.2020.1741400

Chrislando, A. (2019). Pemanfaatan Lingkungan Sekitar Sebagai Media Pembelajaran. *Pepatudzu : Media Pendidikan Dan Sosial Kemasyarakatan*, *15*(1), 1. https://doi.org/10.35329/fkip.v15i1.303

Debrah, J. K., Vidal, D. G., & Dinis, M. A. P. (2021). Raising awareness on solid waste management through formal education for sustainability: A developing countries evidence review. *Recycling*, *6*(1), 1–21. https://doi.org/10.3390/recycling6010006

Fathurohman, I., Amri, M. F., Septiyanto, A., & Riandi. (2023). Integrating STEM based Education for Sustainable Development (ESD) to Promote Quality Education: A Systematic Literature Review. *Jurnal Penelitian Pendidikan IPA*, *9*(11), 1052–1059. https://doi.org/10.29303/jppipa.v9i11.4430

Fischer, D., King, J., Rieckmann, M., Barth, M., Büssing, A., Hemmer, I., & Lindau-Bank, D. (2022). Teacher Education for Sustainable Development: A Review of an Emerging Research Field. In *Journal of Teacher Education* (Vol. 73, Issue 5, pp. 509–524). SAGE Publications Inc. https://doi.org/10.1177/00224871221105784

Fitriati, M., Sahputra, R., & Lestari, I. (2019). Pengaruh pembelajaran berbasis lingkungan terhadap sikap peduli lingkungan pada materi pencemaran lingkungan. *Jurnal Pendidikan Dan Pembelajaran Khatulistiwa*, *8*(1), 1-8. https://doi.org/10.26418/jppk.v8i1.30614

Ghafur, F., & Alviansyah, R. (2025). The Role of Students as Agents of Change Towards Climate Change Action for SDGs. *Entita: Jurnal Pendidikan Ilmu Pengetahuan Sosial Dan Ilmu-Ilmu Sosial*, *1*(SE-Articles), 117–128. http://doi.org/10.19105/ejpis.v1.19139

Hadjichambis, A. C., & Paraskeva-Hadjichambi, D. (2020). Environmental citizenship questionnaire (ECQ): The development and validation of an evaluation instrument for secondary school students. *Sustainability (Switzerland)*, *12*(3). https://doi.org/10.3390/SU12030821

Helmi, M. H., & Herliani, E. (2021). Developing Sustainability Literacy Through STEM Learning: A Review. *SEAQIS Journal of Science Education*, *1*(1), 36–43. https://doi.org/10.58249/sjse.v1i1.23

Kartomiharjo, I. D., Putra, W. H. N., & Purnomo, W. (2019). Analisis dan Perancangan Sistem Informasi Pelaporan Sampah (Studi Kasus pada Dinas Lingkungan Hidup dan Kebersihan Kabupaten Sidoarjo). *Jurnal Pengembangan Teknologi Informasi Dan Ilmu Komputer*, *3*(11), 10756-10764.

Kemper, J. (2021). Stimulating Collective Transformative Learning Experiences with an ESD Whole-School Assessment Tool. *Glocality*, *4*(1), 5. https://doi.org/10.5334/glo.48

Khoiri, A., Sunarno, W., Sajidan, S., & Sukarmin, S. (2021). Analysing students' environmental awareness profile using strategic environmental assessment. *F1000Research*, *10*, 305. https://doi.org/10.12688/f1000research.51523.1

Khoiri, N., Roshayanti, F., & Widarti, R. (2023). Integration of STEAM and ESD: Improving the understanding of fluid concepts and creativity. *Journal of Education and E-Learning Research*, *10*(3), 578–584. https://doi.org/10.20448/jeelr.v10i3.4987

Li, Y. (2018). Study of the effect of environmental education on environmental awareness and environmental attitude based on environmental protection law of the People's Republic of

China. *Eurasia Journal of Mathematics, Science and Technology Education*, *14*(6), 2277–2285. https://doi.org/10.29333/ejmste/86214

Maresi, S. R. P., & Basoeki, A. D. (2024). Upaya meningkatkan kepedulian peserta didik terhadap keberlangsungan lingkungan. *Journal of Character and Environment*, *1*(2), 113–125. https://doi.org/10.61511/jocae.v1i1.2024.474

Miterianifa, M., & Mawarni, M. F. (2024). Penerapan Model Pembelajaran Literasi Lingkungan dalam Meningkatkan Pengetahuan dan Kesadaran Lingkungan. *Jurnal Sains Dan Edukasi Sains*, *7*(1), 68–73. https://doi.org/10.24246/juses.v7i1p68-73

National Research Council. (2012). A framework for K-12 science education: Practices, crosscutting concepts, and core ideas. In *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas*. https://doi.org/10.17226/13165

Owojori, O. M., Mulaudzi, R., & Edokpayi, J. N. (2022). Student's Knowledge, Attitude, and Perception (KAP) to Solid Waste Management: A Survey towards a More Circular Economy from a Rural-Based Tertiary Institution in South Africa. *Sustainability*, *14*(3), 1310. https://doi.org/10.3390/su14031310

Pahnke, J., O'Donnell, C., & Bascopé, M. (2019). Using science to do social good: STEM education for sustainable development. Proceedings of the Second International Dialogue on STEM Education (IDoS), Berlin, Germany, 5-6

Puriana, R. H., Mardhika, R., Mulyono, Faruq, M. M., & Suharti, Abd. Cholid, H. (2021). Meningkatkan Kesadaran Masyarakat Untuk Menjaga Kebersihan Lingkungan Dengan Cara Membuang Sampah Pada Tempatnya Dan Cara Pengelolahan Sampah. *Kanigara*, *1*(2), 173–178. https://doi.org/10.36456/kanigara.v1i2.4076

Rahmadayanti, A., Widodo, A., & Riandi, R. (2025). Is STEM Learning can Significantly Effect Students' Sustainability Awareness? *Jurnal Bioedukatika*, *12*(1), 25–35. https://doi.org/10.26555/bioedukatika.v12i1.28045

Salsabila, L., Purnomo, E. P., & Jovita, H. D. (2021). The Importance of Public Participation in Sustainable Solid Waste Management. *Journal of Governance and Public Policy*, *8*(2). https://doi.org/10.18196/jgpp.v8i2.11519

Sari, P. N. (2016). Analisis Pengelolaan Sampah Padat Di Kecamatan Banuhampu Kabupaten Agam. *Jurnal Kesehatan Masyarakat Andalas*, *10*(2), 157–165. https://doi.org/10.24893/jkma.v10i2.201

Setiawan, N. C. E., Sutrisno, S., Munzil, M., & Danar, D. (2020). Pengenalan STEM (Science, Technology, Engineering, and Mathematics) dan Pengembangan Rancangan Pembelajarannya untuk Merintis Pembelajaran Kimia dengan Sistem SKS di Kota Madiun. *Lumbung Inovasi: Jurnal Pengabdian Kepada Masyarakat*, *5*(2), 56. https://doi.org/10.36312/linov.v5i2.465

Sihombing, R. A., Muslim, M., Rahman, T., & Winarno, N. (2024). Enhancing Quality Education in Indonesia: A Literature Review of STEM-ESD Landscape Contributions. *Journal of Science Learning*, *7*(3), 213–226. https://doi.org/10.17509/jsl.v7i3.69046

UNESCO. (2017). *Education for sustainable development goals: Learning objectives*. UNESCO. https://doi.org/10.54675/cgba9153

Wals, A. E. J. (2014). Sustainability in higher education in the context of the un DESD: A review of learning and institutionalization processes. *Journal of Cleaner Production*, *62*(May), 8–15. https://doi.org/10.1016/j.jclepro.2013.06.007

Wibowo, A. M., Utaya, S., Wahjoedi, W., Zubaidah, S., Amin, S., & Prasad, R. R. (2024). Critical Thinking and Collaboration Skills on Environmental Awareness in Project-Based Science Learning. *Jurnal Pendidikan IPA Indonesia*, *13*(1), 103–115. https://doi.org/10.15294/jpii.v13i1.48561

Yalçın, V. (2022). Design-Oriented Thinking in STEM education: Exploring the Impact on Preschool Children's Twenty-First-Century Skills. *Science & Education*, *33*(4), 901–922. https://doi.org/10.1007/s11191-022-00410-7

Zuhaida, A., Widodo, A., Prima, E. C., & Solihat, R. (2024). Developing Indicators for Science Teacher Competency in Stem-Esd Learning. *Proceedings of International Conference on Education*, *2*(1), 10–17. https://doi.org/10.32672/pice.v2i1.1310