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FOSTERING STUDENT ACTION FOR CLEAN WATER AND SANITATION (SDG-6) THROUGH PROJECT-BASED STEM-ESD LEARNING

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Abstract: The urgency of clean water and sanitation (SDG-6) necessitates a transformative educational approach that bridges environmental knowledge with concrete action. This study evaluates the effectiveness of Project-Based STEM-ESD learning in fostering students' sustainability actions related to SDG-6. Using a quasi-experimental pretest-posttest design, 81 tenth-grade students at a high school in Bandung were divided into an experimental group (N=43) and a control group (N=37) based on a convenience sampling technique. Data were collected through questionnaires that included action indicators (past, present, and future) and competency achievement measures, as well as interviews used as supporting data. Statistical analysis via independent samples t-test showed no significant difference in final mean scores ($p=0.456 > 0.05$). However, a profound shift was observed in behavioral dynamics, where the experimental group dominated the "Positive Change" category (increase in students' posttest scores reflecting a positive shift from past actions to future action plans) (67.44%) compared to the control group (54.06%). The findings indicate a shift in students' mindsets, demonstrating their ability to engage in simple and sustainable actions in their daily lives to prevent and address water-related issues. Thus, STEM-ESD as a pedagogical framework can foster students' future-oriented and concrete actions to address global crises.

Keywords: clean water and sanitation; SDG-6; STEM-ESD learning; sustainability action; water pollution

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INTRODUCTION

Access to clean water and adequate sanitation have an important role in socioeconomic development and impact people's quality of life, including their health and the quality of the environment (Tortajada, 2020). As part of the 2030 Agenda, Sustainable Development Goal 6 (SDG 6) emphasizes shared awareness of sustainable water management. However, evidence on the ground shows that clean water and sanitation remain unresolved issues in Indonesia. In fact, according to data from the United States Agency for International Development (USAID) and Indonesia Urban Water Sanitation and Hygiene (IUWASH), Indonesia ranks last among ASEAN countries in terms of access to urban water and sanitation (Suryani, 2020)**.** One of the causes is the increasing water pollution resulting from domestic and industrial waste, which threatens the stability of the environment in the future. This issue is not only related to the environment, but also to concrete actions taken by the community.

As stated, this kind of action is essential for every individual. This is because when a problem arises, concrete action is needed to resolve it. Concrete action, in this context, is defined as knowledge grounded in the willingness, conviction, or self-confidence to contribute to the resolution, of controversial issues (Sass et al., 2021). Sustainability issues particularly those related to access to clean water and sanitation, as outlined above are among the most controversial issues. Therefore, to address these challenges, every individual must contribute by taking effective action. However, despite the need for concrete action to achieve sustainable goals, it is clear that such action remains insufficient among the general public.

According to a study that has been conducted, many people do not have access to a toilet (Erna et al., 2021). Other studies have also shown that in some rural areas of Indonesia, access to clean water remains a problem. This clean water crisis is caused by slightly turbid water sources and inadequate water distribution systems, which disrupt the supply of clean water to communities. As a result, people have become accustomed to using and consuming water that is not entirely clear (Athallah Y. et al., 2021). The emergence of these issues clearly reflects a lack of concrete action among the public, particularly in achieving the goals of clean water and sanitation.

This lack of concrete action stems from a lack of awareness, knowledge, and concern among the public regarding the importance of hygiene particularly clean water and adequate sanitation (Athallah Y. et al., 2021; Erna et al., 2021; Helmi et al., 2018; Kusumawardhana & Auliya, 2020). This indicates that the existing problems are rooted in an education system that has long prioritized cognitive content and, in practice, is often trapped in a one-way information delivery paradigm. Students may understand the definition of water pollution, but they are not accustomed to actively addressing the issue. This poses a challenge in modern science education: transforming knowledge into consistent behavior. Therefore, a learning process is needed that integrates global issues into local contexts through activities that foster students' problem-solving skills.

One learning model that can be used is the project-based STEM (Science, Technology, Engineering, and Mathematics) learning model incorporating the concept of ESD (Education for Sustainable Development). The STEM learning model is an integrative approach in which students are encouraged to design solutions to real-world problems (Widodo, 2021). However, implementing STEM education without incorporating sustainability values risks fostering innovations that could ultimately harm the environment. The concept of ESD focuses on developing students' understanding of sustainability issues, which will encourage them to make decisions and take actions that are sustainable. These decisions and actions

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must align with the pillars of sustainability: ecological, socially just, and economically viable (Nurfadilah & Siswanto, 2020).

The project-based STEM-ESD learning model allows students to become more engaged in the learning process. As noted in previous research, students engage in exploration during the assigned project activities, making them more active and the learning experience more meaningful (Kristiani et al., 2017). In this context, education is not enough if it merely transmits knowledge, skills, and attitudes; concrete action is also required to put them into practice (Sass et al., 2021). In this way, students not only understand the subject matter but can also act as agents of change to achieve sustainability. Numerous studies have evaluated the effectiveness of STEM education.

Previous research has shown that STEM is an effective learning model for enhancing creative thinking and problem-solving skills (Amin et al., 2022). It is further explained that STEM project-based learning can enhance all aspects of students' STEM literacy, including science literacy, technology literacy, engineering literacy, and mathematics literacy (Kartini et al., 2021). However, most studies still focus on measuring learning outcomes through test scores. Few studies have analyzed students' concrete sustainability actions, which include past actions, present actions, future action plans, and competency achievement. This gap is the primary focus of this study. Often, students possess a high level of knowledge regarding SDG-6, yet they continue to exhibit consumptive behaviors and disregard water waste. Based on this background, this study aims to evaluate the effectiveness of Project-Based STEM-ESD learning in fostering students' sustainability actions related to SDG-6.

METHOD

This study employed a quantitative approach using a quasi-experimental design, specifically the non-equivalent pretest-posttest control group design. The population of this study consisted of 10th-grade students at a high school in Bandung who were studying environmental change. The sample consisted of students in the experimental group (N=43) and students in the control group (N=37). The experimental group was provided with STEM-ESD project-based learning during the learning process, while the control group was not and carried out learning as usually conducted by their teacher, namely discovery learning. The sampling technique used was convenience sampling. The research procedure began with a pretest (O1) to assess the students' initial capacity for action, followed by the intervention phase (X), which involved the development of a sustainable water technology solution project in the experimental group over a period of 5 weeks, and concluded with a posttest (O2) to evaluate the impact of the intervention on students' actual actions regarding SDG-6 issues (Creswell & Gutterman, 2019).

The instrument for measuring students' clean water and sanitation initiatives consists of a non-test item in the form of a 4-point Likert scale questionnaire. This questionnaire was modified and developed based on the research questionnaire (Hadjichambis & Paraskeva-

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Hadjichambi (2020) and the learning objectives for SDG 6 “Clean Water and Sanitation” as outlined in ESD: Learning Objectives (UNESCO, 2017). The action indicators used are, first, past actions; second, present actions; third, future actions; and fourth, competency achievements. Each indicator is integrated with the learning objectives for SDG 6 “Clean Water and Sanitation,” which consists of three domains: cognitive, socio-emotional, and behavioral. It is also integrated with the topics covered in the learning objectives for SDG 6, “Clean Water and Sanitation,” which include water use, water quality and sanitation, and water management. Each statement is presented with four-point scale options. The statements underwent readability testing, followed by validity and reliability testing using SPSS version 26.

The data obtained were analyzed using descriptive statistical tests to determine general information, such as the mean, standard deviation, maximum value, and minimum value. Next, the data underwent prerequisite tests, namely a normality test using the Shapiro-Wilk test and a homogeneity test using Levene’s test. The analysis continued with tests of the difference in means using the Mann-Whitney U test (for pretest data) and the independent samples t-test (for posttest data). This quantitative data was supplemented with additional data obtained from interviews with representatives of each group and the biology teachers.

RESULT AND DISCUSSION

The following presents the results of descriptive and inferential statistical analyses of student performance on Table 1. The results of the pretest data normality and homogeneity test showed that the data were not normally distributed and had the same variance, so it was continued with the Mann-Whitney U test. Meanwhile, the results of the posttest data normality and homogeneity test showed that the data were normally distributed and had the same variance, so it was continued with the Independent Sample T-test. The test results are presented in the table below:

Table 1. Results of the Comparative Test of Students' Mean Action Scores

Data	Group	N	Mean	Std. Dev	Sig. (2-tailed)
Pretest	Experiment	44	2,58	0,33	0,409
	Control	37	2,63	0,36	
Posttest	Experiment	44	2,81	0,31	0,456
	Control	37	2,87	0,31	

Based on Table 1, it is evident that the analysis of students’ pretest performance indicates that there is no significant difference in their initial performance (p-value $_{(0.409)} > \alpha_{(0.05)}$). Furthermore, the posttest revealed that there were no significant differences regarding the students' final performance (p-value $_{(0.456)} > \alpha_{(0.05)}$). The results indicate that the initial and final behaviors of students regarding clean water and sanitation in both the experimental and control groups were comparable or equivalent. The findings of this study are noteworthy.

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The lack of statistical significance in these mean scores does not imply a failure of the instructional model, but rather reflects a common phenomenon in educational research that examines affective and behavioral variables within a limited intervention period.

This is consistent with previous research showing that sustainable behavior is not merely an instant cognitive achievement, but rather the result of a complex process involving beliefs and awareness of sustainability values. It often takes longer to bring about tangible change (Ásványi & Gedeon, 2025). In addition, this is supported by the finding that project-based learning periods lasting 9–18 weeks have a significant impact on student learning outcomes (Zhang & Ma, 2023). Therefore, clear that student behavior cannot be easily changed or significantly improved in a short period of time. In addition to testing the difference in means, further data analysis was conducted by comparing behavioral dynamics or changes in students' patterns of behavior.

These changes in actions are classified into four categories based on changes from the past, the present, and future plans. These categories include positive, negative, and no patterned behavior changes, and no change at all. The percentages of students' behavior change patterns are presented in the table below:

Table 2. Percentage of Action Change Patterns

No	Category of Change Patterns	Experiment (N=43)	Control (N=37)
1	Positive change	67,44%	54,06%
2	Negative change	2,33%	0%
3	No patterned behavior changes	30,23%	43,24%
4	No change at all	0%	2,70%

The data in Table 2 shows that the majority of students in both classes experienced positive transitions. However, the experimental group demonstrated a more dominant percentage of positive change action patterns at 67.44%. These results provide evidence that integrating Science, Technology, Engineering, and Mathematics (STEM) with Education for Sustainable Development (ESD) principles can trigger action intent. This learning not only provides knowledge, but also provides experience of technological engineering through STEM and the moral orientation that underlies such actions is urgent.

In the implementation of STEM-ESD project learning, students are given the opportunity to directly experience the learning processes that occur according to the stages of the applied learning model. This is in line with research findings that state that when students observe a phenomenon and then directly experience the event or phenomenon, an attitude is formed in them (Widodo, 2021). Previous research has shown that when students have the opportunity to engage in direct observation of the environment to carry out a project, it can increase their awareness and involvement in environmental issues. This can then motivate students to take concrete action (Barrón et al., 2022; Yeşilyurt et al., 2020).

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In addition to the observation phase, students are also motivated to take action during the "think and create" phase that is, when they devise and develop appropriate technological solutions to address water and sanitation issues. Through these activities, students can apply the knowledge they have gained and create appropriate solutions to existing problems. Previous findings also indicate that prototype development in project-based learning is known as "learning by making," a process that encourages students to think critically, collaborate, and develop innovative solutions to real-world problems. Furthermore, students can learn from reflection and direct experience during project implementation. (Petrakis et al., 2021). Other studies have also confirmed that student involvement in water management projects can increase students' awareness of and action on water issues (Zyoud & Zyoud, 2023). The analysis was not limited to the overall average score; it also examined the average score for each action indicator.

The mean scores for each action indicator (Past Actions, Present Actions, Future Actions Plan, and Competency Achievement) were mapped to identify specific areas of improvement.

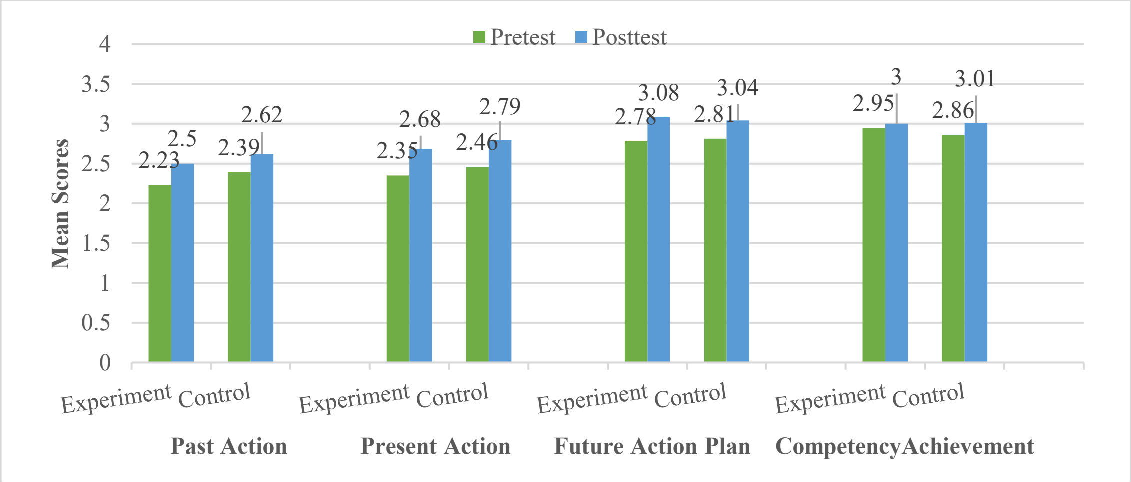

Figure 1. Mean Scores per Action Indicator

Based on the data in Fugire 1, the highest score increase was in the "Present Action" indicator. The graph shows that the experimental group showed a higher score increase compared to the control group in the past action and future action plan indicators. Past actions can be considered part of students' experiences. Furthermore, past actions can also serve as an indicator of students' knowledge. This is because an action may occur as a result of existing knowledge. As stated in previous research, students' actions are influenced by the community's awareness, knowledge, and concern regarding the importance of hygiene particularly clean water and adequate sanitation. (Erna et al., 2021; Green & Kreuter, 2010; Helmi et al., 2018; Kusumawardhana & Auliya, 2020). The increase in the high average score

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for past actions in the experimental group was due to the fact that the students had already gained more knowledge related to clean water and sanitation through STEM-ESD learning.

The highest increase in average scores was observed in the "Present Action" indicator among both the experimental and control groups. This increase is believed to be due, in part, to the students' awareness and willingness to take action. As noted in previous research, action cannot be forced upon others, but it occurs when individuals possess the willingness, conviction, and self-confidence to take such action (Sass et al., 2021). Other studies also indicate that self-awareness regarding environmental issues is the first step toward taking action or engaging in sustainable practices (Mastria et al., 2023). Although the increase was the same, an analysis of changes in students' action patterns indicates a positive shift from past behavior toward current behavior, which was pronounced in the experimental group.

A more significant improvement was also observed in the "future action plan" indicator, which refers to plans for future actions. In the designed learning process, students are encouraged to plan, create, and test technological solutions to address existing water-related issues. These activities serve as hands-on experiences in problem-solving and the implementation of environmentally conscious actions. This is supported by research findings indicating that STEM learning processes are conducted using a problem-solving approach. Furthermore, the integration of ESD concepts into STEM projects is deemed effective in fostering greater environmental appreciation among students (Widodo, 2021; Fitrianur & Hamdu, 2021). As a result, this learning experience inspires students to take concrete action in the future.

However, regarding the competency achievement indicator, the control group's average score showed a greater increase. This was due to the factor of self-confidence in the ability to carry out sustainable actions. As stated, self-confidence serves as a motivator for effort, self-regulation, and achievement, including students' actions (Freire et al., 2020). In addition, it was also found that students with high self-confidence tend to employ more in-depth cognitive processing strategies than students with lower self-confidence (Nabil Rayyan et al., 2025). Thus, it can be said that students still engage in more in-depth cognitive processing before deciding on a course of action, particularly when it comes to water management.

Based on observations of the learning process, the results provide qualitative confirmation that students' active involvement in designing water technology solutions contributes to a high degree of positive behavioral change. The "learning by doing" experience provides concrete evidence to students that complex environmental challenges can be addressed through simple yet functional technological innovations. This aligns with UNESCO (2017) mandate for sustainable education, which states that pedagogical processes must go beyond the cognitive domain to address the socio-emotional and behavioral domains. Students' success in creating real solutions provides psychological reinforcement that they are indeed agents of change with high self-efficacy. Furthermore, this active engagement serves to bridge the gap between creative ideas and practical application.

This was evident in some students who were less engaged in learning activities or whose groups demonstrated low levels of action. However, as previously mentioned, in addition to engagement in learning, interest, motivation, and readiness are also factors contributing to the lack of improvement in student action. This is supported by interview results with students, which indicate that students are not yet accustomed to carrying out water management actions, particularly those covered in the lessons. This aligns with existing research indicating that student readiness plays a crucial role in encouraging participation in activities, where student readiness encompasses aspects of alternative learning, technological skills, and self-motivation (Wut et al., 2022). Thus, project-based STEM-ESD learning integration can serve as an effort to cultivate students' mindset in addressing global issues sustainably.

CONCLUSION

Based on the results of the analysis and discussion, it can be concluded that the implementation of a project-based STEM-ESD learning model is quite effective in encouraging students' sustainable actions related to SDG-6. The STEM-ESD learning model triggers changes in behavior. These changes demonstrate a clear shift from merely knowing about the issue, to attempting to take action, and finally to planning future actions. This success is driven by the integration of STEM learning which builds experience and problem-solving skills and ESD concepts, which reinforce moral responsibility as environmentally conscious citizens. Hands-on experience in designing appropriate technological solutions not only enhances creativity and engineering skills but also transforms cognitive understanding into the willingness and conviction to take concrete action regarding phenomena occurring in the surrounding environment. Consequently, this learning model successfully facilitates a shift in students from being mere observers of environmental issues to becoming proactive agents of change in ensuring the sustainability of water resources in the future.

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