

STEAM-Based Eco-Green Mathematics for Junior High School Students' Environmental Mathematical Literacy

Sunismi¹, Raden Roro Ettie Rukmigarsari², and Abdul Halim Fathani³

¹²³ Department of Mathematics Education, Islamic University of Malang, Indonesia

*Corresponding author: sunismi@unisma.ac.id

ABSTRACT

Environmental issues require mathematics learning that connects mathematical reasoning with real-life ecological contexts. Eco-Green Mathematics through the STEAM (Science, Technology, Engineering, Arts, and Mathematics) approach offers interdisciplinary learning that helps students understand environmental problems through mathematical concepts, data interpretation, and contextual problem-solving. This study aimed to explore the effect of Eco-Green Mathematics learning through STEAM on the environmental mathematical literacy of Madrasah Tsanawiyah (MTs) students. A mixed-methods approach with a sequential explanatory design was employed, beginning with quantitative data collection and analysis, followed by qualitative data collection and analysis to explain the quantitative findings. This research was conducted at one of the MT in Malang, involving 31 students, namely 16 students in the experimental class and 15 students in the control class. Quantitative data were obtained from students' environmental mathematical literacy pretest and posttest results and analyzed descriptively and comparatively using independent sample t-test and paired sample t-test. Qualitative data were collected through student responses and interviews. The independent sample t-test showed a significant value of 0.007 (< 0.05), indicating a significant difference in mean environmental mathematical literacy between the experimental and control classes. The paired sample t-test in the experimental class showed a significance value of 0.000 (< 0.05), indicating a significant difference before and after treatment. Qualitative findings supported the quantitative results, showing that students became more active, reflective, and aware of environmental issues during mathematics learning. Therefore, Eco-Green Mathematics learning through STEAM is a relevant approach to support MTs students' environmental mathematical literacy by integrating environmental contexts, STEAM activities, and data-based reasoning.

Keywords : Eco-Green Mathematics, STEAM, Environmental Mathematical Literacy

1. INTRODUCTION

Environmental issues, such as climate change, pollution, energy consumption, and waste management, have become increasingly complex global challenges and require students' ability to understand and respond to various sustainability issues in an evidence-based manner (UNESCO, 2020). These various problems are generally presented in the form of data, graphs, tables, and quantitative information so that students are able to use mathematical concepts to interpret, analyze, and evaluate environmental phenomena in a real-world context (OECD, 2023). Within the framework of mathematical literacy, the ability to use mathematics is not only limited to solving mathematical problems, but also includes the ability to formulate, apply, and interpret mathematics to make appropriate decisions in various life situations (OECD, 2023). Therefore, mathematics learning needs to develop skills that integrate mathematical literacy with the environmental context, which in this study is termed as Environmental

Mathematical Literacy, which is the ability of students to use mathematical knowledge and skills to understand, analyze, evaluate, and make decisions on various environmental problems responsibly. Integrating sustainability contexts into mathematics learning has also been reported to increase the linkage of mathematics concepts with real problems and encourage student involvement in solving environmental issues through meaningful approaches (Arik Karamık, 2023; Karjanto, 2023).

Building on this perspective, Environmental Mathematical Literacy (EML) refers to students' ability to use mathematical knowledge and reasoning to understand, analyze, evaluate, and make responsible decisions regarding environmental problems (Sunismi et al., 2026). This ability involves students' capacity to represent and reason about socio-ecological problems through mathematical perspectives (Fuadah & Shodikin, 2026). Furthermore, mathematics education for sustainable development emphasizes the importance of connecting mathematical modeling with sustainability issues to support students in understanding complex environmental phenomena (Borromeo Ferri & Bulut, 2026; Stillman et al., 2020). In this study, EML is viewed through students' ability to formulate environmental problems mathematically, employ mathematical concepts and procedures, interpret mathematical results in environmental contexts, and propose relevant environmental actions. Therefore, mathematics learning should not be limited to procedural knowledge and abstract calculations but should provide meaningful opportunities for students to apply mathematical concepts in authentic environmental contexts.

However, mathematics learning in schools is still frequently dominated by procedural activities, formula-based exercises, and abstract problem-solving. Although students may achieve success in solving routine mathematical tasks, they often experience difficulties when applying mathematical concepts to real-life situations, including environmental problems. Mathematical literacy requires students not only to perform calculations but also to formulate problems, employ mathematical strategies, interpret results, and use mathematical reasoning for decision-making (OECD, 2023). This limitation becomes more critical when students are expected to interpret environmental data, construct mathematical representations, and justify decisions related to sustainability issues. Therefore, integrating environmental contexts into mathematics learning can provide meaningful experiences that encourage students to develop mathematical understanding while increasing awareness of sustainability issues (Makramalla et al., 2025).

One learning approach that can support this integration is Eco-Green Mathematics, which positions mathematics as a tool for understanding environmental phenomena and developing sustainable solutions. Eco-Green Mathematics connects mathematical concepts with environmental contexts through activities involving measurement, data analysis, mathematical modeling, prediction, and decision-making. Previous studies indicate that effective implementation of Eco-Green Mathematics requires appropriate learning designs, systematic instructional materials, and teacher readiness to support meaningful learning

experiences (Sunismi et al., 2026). Through mathematical modeling activities, students can represent, analyze, and interpret environmental problems using mathematical concepts, enabling them to connect abstract mathematical ideas with real-world sustainability challenges (Bulut & Borromeo Ferri, 2025). Moreover, mathematical modeling education provides opportunities for students to engage with authentic sustainability issues and develop problem-solving abilities (Stillman et al., 2020). Thus, Eco-Green Mathematics provides not only environmental contexts for learning mathematics but also a pedagogical pathway for developing students' Environmental Mathematical Literacy.

To strengthen the interdisciplinary characteristics of Eco-Green Mathematics, the STEAM (Science, Technology, Engineering, Arts, and Mathematics) approach provides a relevant learning framework. STEAM emphasizes interdisciplinary connections, inquiry-based investigation, creativity, collaboration, and the development of solutions to authentic problems. Previous studies have demonstrated that STEAM learning supports interdisciplinary thinking and sustainability-oriented education (Djam'an, 2025; Marín-Marín et al., 2021). Through STEAM activities, students can investigate environmental issues through inquiry processes (Baptista et al., 2025), process information and develop creative products (Filipe et al., 2024), and integrate scientific, technological, engineering, artistic, and mathematical perspectives to solve real-world problems (Perignat & Katz-Buonincontro, 2019). In mathematics education, integrated STEM/STEAM learning has been shown to support mathematical literacy development through contextual and problem-based learning activities (Cahyono et al., 2025; English, 2016). Furthermore, project-based learning principles, when integrated into STEAM activities, can promote active exploration, collaboration, mathematical literacy, and character development (Kokotsaki et al., 2016; Supianti et al., 2025). Sustainability-oriented STEAM activities have also demonstrated potential in improving students' environmental attitudes, recycling behaviors, and design thinking skills (Karakuyu & Karafil, 2026).

Although previous studies have provided important contributions to STEAM education, environmental education, and mathematical literacy development, these areas have generally been investigated separately. Research on STEAM learning has mainly focused on creativity, innovation, design thinking, and interdisciplinary learning, while its role in developing Environmental Mathematical Literacy remains limited (Amanova et al., 2025). Similarly, many mathematical literacy studies have emphasized general mathematical competencies, while environmental contexts have not yet become a central focus of investigation (Kappassova et al., 2025). In addition, studies integrating authentic environmental problems into mathematics learning at the junior high school or Madrasah Tsanawiyah (MTs) level are still limited (Halawa et al., 2024).

Based on these limitations, a research gap exists regarding the integration of Eco-Green Mathematics, STEAM learning, and Environmental Mathematical Literacy in junior high school mathematics education. Previous studies have examined STEAM learning, mathematical literacy, and environmental education independently; however, limited studies

have investigated how Eco-Green Mathematics integrated with STEAM activities can support students' Environmental Mathematical Literacy using a mixed-methods sequential explanatory design. Therefore, this study contributes to filling this gap by implementing STEAM-based Eco-Green Mathematics in MTs mathematics learning through environmental contexts related to water consumption for ablution, electricity use, and plant ecosystems within the topic of Linear Equations, while examining both quantitative learning outcomes and qualitative learning experiences.

Based on this research gap, this study employs a mixed-methods sequential explanatory design to obtain a comprehensive understanding of STEAM-based Eco-Green Mathematics learning. The quantitative phase examines differences in Environmental Mathematical Literacy between students who participate in STEAM-based Eco-Green Mathematics learning and students who receive conventional mathematics learning. The qualitative phase analyzes students' posttest responses and explores students' thinking processes through in-depth interviews with high, medium, and low achievement students. The integration phase combines quantitative and qualitative findings to explain how STEAM-based Eco-Green Mathematics supports students' Environmental Mathematical Literacy development.

Therefore, this study aims to: (1) analyze differences in Environmental Mathematical Literacy between MTs students who participate in STEAM-based Eco-Green Mathematics learning and students who receive conventional mathematics learning; (2) describe students' Environmental Mathematical Literacy processes based on the indicators of formulate, employ, interpret, and environmental action through analysis of students' posttest responses and interviews across different achievement levels; and (3) integrate qualitative findings to explain and strengthen quantitative results regarding the contribution of STEAM-based Eco-Green Mathematics learning in supporting students' Environmental Mathematical Literacy.

2. METHODS

This study employed a mixed methods approach with a sequential explanatory design (Christodoulou, 2025; Gierus et al., 2025). This design consisted of three stages: quantitative, qualitative, and data integration stages. The quantitative stage aimed to examine the effect of STEAM-based Eco-Green Mathematics learning on students' Environmental Mathematical Literacy (EML) through pretest and posttest measurements. The qualitative stage was conducted to provide a deeper explanation of the quantitative findings through the analysis of students' posttest responses and in-depth interviews. The final stage involved integrating quantitative and qualitative findings to obtain a more comprehensive understanding of the effect of the implemented learning approach.

The research was conducted from May to June 2026 involving eighth-grade students at one of the Madrasah Tsanawiyah (MTs) in Malang Regency. The population consisted of two classes, namely class VIII-A with 16 students and class VIII-B with 15 students, resulting in a

total population of 31 students. The sampling technique used was total sampling, which involves selecting all members of the population as research participants because the population size is relatively small and all members are considered capable of providing the required information (Firmansyah & Dede, 2022). Therefore, all students in the population were included as research samples, consisting of 16 students in the experimental class and 15 students in the control class. The experimental class received STEAM-based Eco-Green Mathematics learning, while the control class received conventional mathematics instruction. Both classes were given a pretest before the learning process and a posttest after the learning process to measure students' Environmental Mathematical Literacy.

Quantitative Stage

The quantitative stage aimed to determine the differences in students' Environmental Mathematical Literacy between the experimental and control classes after the treatment. The research instrument was a numeracy literacy test consisting of two contextual essay questions developed based on EML indicators, namely: (1) using numbers and basic mathematical symbols to solve everyday problems, (2) analyzing information presented in various forms such as graphs, tables, and diagrams, and (3) interpreting analysis results to make predictions and decisions. The instrument was validated by two experts in mathematics education and environmental-based learning to ensure its content validity.

The experimental class received learning treatment for six meetings using the STEAM-based Eco-Green Mathematics approach on the topic of Linear Equations. Meanwhile, the control class also participated in six meetings using conventional mathematics learning with the same topic. In the experimental class, learning activities integrated mathematical concepts with environmental issues surrounding the school, such as water usage for ablution, electricity consumption, and the existence of plants. The learning stages included: (1) identifying environmental problems, (2) collecting and identifying environmental data, (3) determining mathematical variables and relationships, (4) applying linear equation concepts to analyze problems, (5) representing variable relationships through graphs, (6) conducting analysis and predictions based on mathematical models, (7) integrating STEAM elements, (8) designing environmentally friendly solutions, (9) communicating analysis results, and (10) reflecting on the application of mathematics in environmental contexts.

Quantitative data were analyzed using SPSS 25 and Minitab 19. The analysis began with a normality test as a prerequisite test to determine data distribution. Furthermore, an independent sample t-test was conducted using SPSS 25 to examine differences in Environmental Mathematical Literacy between the experimental and control classes. A paired sample t-test was also conducted using Minitab 19 to determine students' improvement before and after the learning intervention in each class.

In addition to significance testing, an effect size analysis using Cohen's *d* was calculated to determine the magnitude of the difference between the experimental and control classes. Reporting effect size complements statistical significance testing by providing information

about the practical importance of the observed differences and facilitating the interpretation of research findings (Lakens, 2013). Cohen's d values were interpreted using commonly accepted benchmarks, where 0.20, 0.50, and 0.80 indicate small, medium, and large effects, respectively, when no field-specific benchmarks are available (Brydges, 2019).

Qualitative Stage

The qualitative stage was conducted to obtain a deeper understanding of students' Environmental Mathematical Literacy after participating in STEAM-based Eco-Green Mathematics learning. Qualitative data were obtained from two sources: the analysis of students' posttest responses and in-depth interviews with selected students.

The analysis of posttest responses focused on examining students' thinking processes in solving environmental contextual problems based on EML indicators. The analysis included students' abilities to understand and formulate problems, use mathematical information and concepts, perform calculations, interpret results, and use analytical results to make predictions and decisions related to environmental problems. This analysis aimed to identify students' problem-solving strategies, conceptual understanding, and ability to connect mathematical concepts with environmental contexts.

In addition, in-depth interviews were conducted with three students selected through purposive sampling based on posttest results. The participants consisted of one student with high achievement, one student with medium achievement, and one student with low achievement. The selection of these participants aimed to obtain insights into variations in students' thinking strategies, learning experiences, and understanding in solving Environmental Mathematical Literacy problems.

The interview data were analyzed using thematic analysis through several stages, including reading and understanding interview transcripts, identifying important information, conducting coding, grouping codes into themes, and interpreting themes based on EML indicators. Data validity was ensured through triangulation by comparing the results of posttest response analysis and student interview findings.

Data Integration Stage (Mixed Methods)

The integration stage was conducted by connecting the quantitative and qualitative findings. Statistical test results were used to determine the effect of STEAM-based Eco-Green Mathematics learning on Environmental Mathematical Literacy, while the analysis of students' responses and interviews was used to explain students' thinking processes, problem-solving strategies, and learning experiences during the learning process.

The flow of STEAM-based Eco-Green Mathematics research with a sequential explanatory mixed methods design is clearly presented in Figure 1 below.

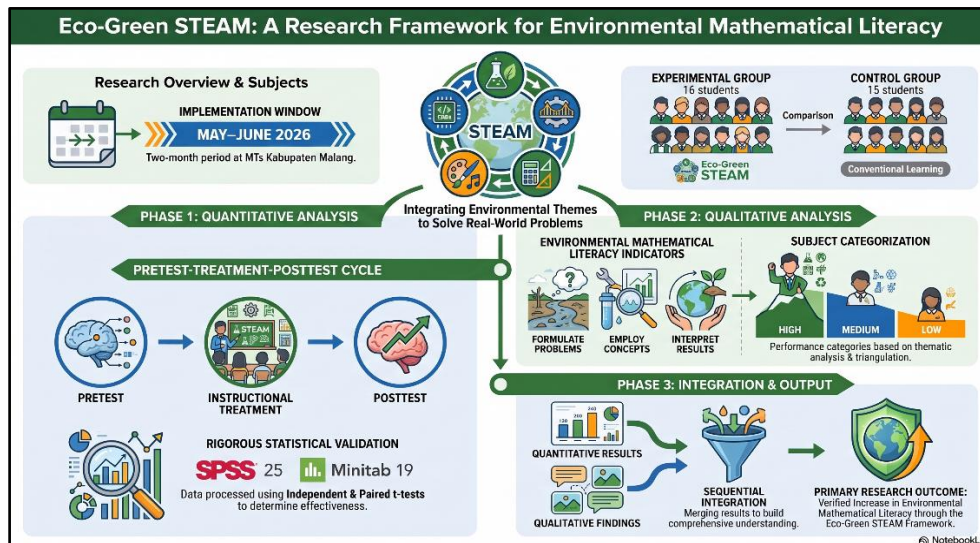


Figure 1. Research Flow of STEAM-Based Eco-Green Mathematics Using a Sequential Explanatory Mixed Methods Design

3. RESULT & DISCUSSION

The results of this study are presented based on the sequential explanatory mixed methods design, consisting of quantitative analysis, qualitative analysis, and integration of both findings. The quantitative analysis was conducted to examine differences in students' Environmental Mathematical Literacy (EML) between the experimental and control classes. Meanwhile, qualitative analysis was conducted to explain the quantitative findings through analysis of students' posttest responses and in-depth interviews. The integration stage was performed by connecting quantitative and qualitative findings to obtain a comprehensive understanding of how STEAM-based Eco-Green Mathematics learning supported students' Environmental Mathematical Literacy development.

Quantitative Results

The quantitative results were obtained from students' pretest and posttest scores of Environmental Mathematical Literacy. The quantitative analysis was conducted using a normality test, independent sample t-test, paired sample t-test, and effect size analysis using Cohen's d. The analysis was performed using SPSS 25 and Minitab 19.

Before the learning intervention, a pretest was administered to both classes to identify students' initial Environmental Mathematical Literacy abilities. The results indicated that both classes had comparable initial abilities before the implementation of the learning treatment. The experimental class received STEAM-based Eco-Green Mathematics learning for six meetings on the topic of Linear Equations, while the control class received conventional mathematics learning with the same topic. After the intervention, both classes completed a posttest to measure changes in Environmental Mathematical Literacy.

Table 1. Normality Test Results of Posttest Data

Class	Statistics	df	Sig.	Interpretation
Experiment	0.927	16	0.215	Normally distributed
Control	0.890	15	0.068	Normally distributed

Based on Table 1, the significance values of the posttest data for both classes were greater than 0.05. Therefore, the posttest data fulfilled the assumption of normal distribution and could be analyzed using parametric statistical tests.

Table 2. Independent Sample t-Test Results of Posttest Scores

Class	N	Mean	Standard Deviation	Sig. (2-tailed)	Cohen's d
Experiment	16	69.044	14.4667	0.007	1.04
Control	15	54.400	13.8013		

The independent sample t-test results presented in Table 2 showed a significance value of $0.007 < 0.05$, indicating a difference in Environmental Mathematical Literacy posttest scores between the experimental and control classes. The experimental class obtained a higher mean posttest score (69.044) compared with the control class (54.400).

Furthermore, the effect size analysis using Cohen's d resulted in a value of 1.04, indicating a large effect. This finding suggests that the difference between the experimental and control classes was not only statistically significant but also represented a meaningful difference in Environmental Mathematical Literacy achievement within the context of the participating MTs students.

Table 3. Paired Sample t-Test Results of Experimental Class

Test	N	Mean	Standard Deviation	Sig. (1-tailed)
Pretest	16	35.031	16.5616	0.000
Posttest	16	69.044	14.4667	

Table 3 shows that the paired sample t-test obtained a significance value of $0.000 < 0.05$, indicating a significant improvement in students' Environmental Mathematical Literacy after participating in STEAM-based Eco-Green Mathematics learning. The increase from the pretest mean score (35.031) to the posttest mean score (69.044) indicates that the learning approach supported students in applying mathematical concepts to environmental problems.

Qualitative Results

The qualitative findings were obtained from two sources: analysis of students' posttest responses and in-depth interviews with selected students. The qualitative analysis was conducted to explain the quantitative findings by examining students' thinking processes and strategies in solving environmental contextual problems.

The analysis of posttest responses focused on examining students' thinking processes based on Environmental Mathematical Literacy indicators. The analysis included students' abilities to understand and formulate environmental problems, use mathematical information and concepts, perform calculations, interpret results, and use analytical results to make predictions and decisions related to environmental issues. This analysis aimed to identify

students' problem-solving strategies, conceptual understanding, and ability to connect mathematical concepts with environmental contexts.

The interview data were obtained from three students selected through purposive sampling based on posttest results, consisting of one student from the high achievement group, one student from the medium achievement group, and one student from the low achievement group. Since each category was represented by only one interviewed student, the findings are interpreted as individual learning patterns that explain the quantitative results rather than general characteristics of all students in each category.

Environmental Mathematical Literacy of the High Achievement Student

The interviewed student from the high achievement group demonstrated the ability to connect environmental problems with mathematical representations. In the formulate indicator, the student was able to identify relevant environmental information, determine variables, and represent the relationship between variables using mathematical models. In the employ indicator, the student demonstrated the ability to use tables, graphs, gradients, and linear equations to analyze environmental data. The student was also able to perform calculations accurately and select appropriate mathematical procedures. In the interpret indicator, the student was able to explain the meaning of mathematical results in relation to environmental conditions. Furthermore, in the environmental action indicator, the student was able to propose solutions based on mathematical analysis, such as strategies for reducing resource consumption and improving environmental management.

These findings explain the quantitative results showing higher posttest achievement in the experimental class. The ability of the interviewed student to transform environmental problems into mathematical models indicates that STEAM-based Eco-Green Mathematics learning supported meaningful mathematical reasoning.

Environmental Mathematical Literacy of the Medium Achievement Student

The interviewed student from the medium achievement group demonstrated developing Environmental Mathematical Literacy abilities. The student was able to identify environmental problems and use basic mathematical information; however, the student still required guidance when constructing mathematical models and selecting appropriate strategies. The student demonstrated the ability to perform calculations and interpret simple representations, but showed limitations in explaining mathematical relationships within environmental contexts. The student was also able to suggest environmental actions, although the proposed solutions were not fully supported by mathematical analysis.

These findings indicate that STEAM-based Eco-Green Mathematics learning provided opportunities for students to develop EML, although some students still required additional support, particularly in mathematical modeling and interpretation processes.

Environmental Mathematical Literacy of the Low Achievement Student

The interviewed student from the low achievement group showed difficulties in several aspects of Environmental Mathematical Literacy. The student was able to recognize

environmental problems but experienced challenges in translating environmental situations into mathematical representations. The student required guidance when applying mathematical concepts, performing calculations, and interpreting results. The environmental solutions proposed by the student were generally based on daily experiences rather than mathematical analysis.

These findings provide additional explanation of the quantitative results by showing that students developed Environmental Mathematical Literacy at different levels depending on their existing mathematical reasoning abilities.

Integration of Quantitative and Qualitative Findings

The integration stage was conducted according to the principles of the sequential explanatory mixed methods design, in which qualitative findings were used to explain and strengthen quantitative results.

Table 4. Integration of Quantitative and Qualitative Findings

Component	Quantitative Findings	Qualitative Explanation	Integrated Interpretation
Learning outcomes	The independent sample <i>t</i> -test showed a significant difference between the experimental and control classes (Sig. = 0.007 < 0.05). The experimental class obtained a higher mean posttest score (69.044) than the control class (54.400), with a large effect size (Cohen's <i>d</i> = 1.04).	Analysis of posttest responses and interviews showed that students were able to connect environmental problems with mathematical representations, including tables, graphs, gradients, and linear equations.	STEAM-based Eco-Green Mathematics learning supported students in applying mathematical concepts to environmental problems within the context of the study.
Learning improvement	The paired sample <i>t</i> -test showed significant improvement in the experimental class (Sig. = 0.000 < 0.05).	The interviewed students demonstrated different levels of ability in formulating problems, employing mathematical concepts, interpreting results, and proposing	The improvement occurred because learning activities provided opportunities for students to practice mathematical reasoning through authentic

Component	Quantitative Findings	Qualitative Explanation	Integrated Interpretation
		environmental actions.	environmental contexts.
Mathematical reasoning process	Quantitative results indicated improved Environmental Mathematical Literacy after the intervention.	The high-achievement student demonstrated stronger mathematical modeling abilities, while medium- and low-achievement students showed developing abilities and required further guidance.	Qualitative findings explained how STEAM-based Eco-Green Mathematics influenced students' reasoning processes during environmental problem-solving.

Based on Table 4, the quantitative and qualitative findings complement each other. The statistical results demonstrated that students in the experimental class obtained higher Environmental Mathematical Literacy outcomes compared with students in the control class, with a large effect size indicating a meaningful difference within the research context. Meanwhile, qualitative findings explained that these differences were supported by students' abilities to transform environmental problems into mathematical representations, apply mathematical concepts, interpret results, and develop environmental solutions.

Therefore, the integration of findings suggests that STEAM-based Eco-Green Mathematics learning may support the development of students' Environmental Mathematical Literacy by combining environmental contexts, mathematical modeling, and interdisciplinary STEAM activities.

DISCUSSION

The findings of this study suggest that STEAM-based Eco-Green Mathematics learning may support the development of students' Environmental Mathematical Literacy (EML) within the context of the participating MTs. The quantitative results showed that the experimental class obtained a higher posttest mean score (69.044) compared with the control class (54.400), with a significance value of $0.007 < 0.05$. In addition, the effect size analysis using Cohen's d resulted in a large effect size ($d = 1.04$), indicating that the difference between the two classes represented a meaningful difference in Environmental Mathematical Literacy achievement. Furthermore, the paired sample t -test showed a difference between students' pretest and posttest scores in the experimental class, with the mean score increasing from 35.031 in the pretest to 69.044 in the posttest ($p < 0.001$). These findings suggest that integrating environmental contexts with STEAM activities provided students with opportunities to apply mathematical concepts in meaningful and contextual learning situations.

The observed improvement may be attributed to the contextual characteristics of STEAM-based Eco-Green Mathematics learning, which allowed students to engage with authentic environmental problems, analyze environmental data, construct mathematical representations, and develop solutions based on mathematical reasoning. The large effect size may indicate that the learning activities provided meaningful experiences for students to connect mathematical concepts with real environmental situations. Unlike conventional mathematics learning, which often emphasizes procedural calculations, this approach encouraged students to engage in the processes of identifying problems, determining mathematical variables, constructing models, interpreting results, and making decisions related to environmental issues. Through these activities, students were not only learning mathematical concepts but also developing the ability to use mathematics as a tool for understanding and responding to environmental phenomena.

This finding is consistent with Cahyono et al. (2025), who emphasized that STEM and technology-based contexts support the development of mathematical literacy through meaningful learning experiences. Similarly, (Susanta et al., 2025) demonstrated that STEAM inquiry modules can support students' literacy development by involving investigation and problem-solving activities. The present findings also support (Supianti et al., 2025), who reported that project-based STEAM learning contributes to mathematical literacy and student character development through active exploration and collaboration. Furthermore, contextual and challenge-based mathematics learning encourages students to apply mathematical knowledge in solving authentic problems (Meilina et al., 2026), while problem-based learning can improve mathematical literacy by considering students' initial abilities (Hasanah et al., 2026). The results are also consistent with (Rahmadini & Sari, 2025), who showed that STEAM project-based modules support numeracy literacy through active and applicable learning activities. These findings strengthen the results of (Thomas & Larwin, 2023), who confirmed the contribution of STEM education to secondary students' learning development, and (Amanova et al., 2025), who highlighted the potential of STEAM in creating interdisciplinary and meaningful learning environments.

The role of Eco-Green Mathematics in supporting students' Environmental Mathematical Literacy can be explained through its emphasis on connecting mathematical concepts with environmental phenomena. In this study, students analyzed environmental contexts related to water consumption, electricity use, and plant ecosystems through the topic of Linear Equations. These contexts encouraged students to identify variables, analyze relationships between variables, construct mathematical representations, and use equations and graphs to predict environmental conditions. Thus, Eco-Green Mathematics functioned as a bridge between abstract mathematical concepts and real environmental problems. This finding supports (Sunismi et al., 2026), who emphasized the relationship between Eco-Green Mathematics and environmental sustainability literacy, and (Bulut & Borromeo Ferri, 2025), who positioned mathematical modeling as a link between mathematical concepts and

sustainability issues. Similarly, (Stillman et al., 2020) highlighted that mathematical modeling provides opportunities for students to engage with authentic sustainability challenges and develop problem-solving abilities.

The qualitative findings further explain how STEAM-based Eco-Green Mathematics supported students' Environmental Mathematical Literacy development. Based on the analysis of posttest responses and interviews, the interviewed student from the high achievement group demonstrated the ability to transform environmental problems into mathematical models, use tables, coordinates, graphs, gradients, and equations, interpret mathematical results, and propose environmental actions based on analysis. This ability reflects the role of mathematical modeling in connecting environmental issues with mathematical reasoning. These findings are consistent with (Bulut & Borromeo Ferri, 2025), who emphasized the importance of modeling activities in sustainability-oriented mathematics education, and (Eka et al., 2026), who highlighted the importance of literacy activities in Linear Function learning.

Meanwhile, the interviewed student from the medium achievement group demonstrated developing abilities in performing calculations and interpreting simple mathematical information but still required guidance in constructing models, selecting strategies, and representing data graphically. The interviewed student from the low achievement group showed difficulties in translating environmental situations into mathematical representations and interpreting mathematical results without guidance. These differences indicate that the development of Environmental Mathematical Literacy is influenced not only by learning approaches but also by students' initial mathematical abilities, reasoning characteristics, learning experiences, and ability to represent problems mathematically. This finding supports (Wardani et al., 2024), who reported that students may experience different difficulties during the mathematical literacy process, particularly in formulating, employing, and interpreting solutions. It is also consistent with (Kappassova et al., 2025) and (Fuadah & Shodikin, 2026), who emphasized that students' mathematical reasoning in socio-ecological contexts develops through different cognitive processes.

The differences among students also indicate the importance of providing appropriate scaffolding during STEAM-based Eco-Green Mathematics learning. Students with stronger mathematical foundations may directly connect environmental information with mathematical models, while students with developing abilities require additional support in identifying variables, selecting mathematical procedures, and interpreting results. Therefore, STEAM-based Eco-Green Mathematics should not only provide authentic problems but also include structured guidance to support students with different levels of mathematical readiness.

The development of the environmental action indicator further demonstrates the contribution of project-based STEAM activities. The interviewed student from the high achievement group was able to propose environmental actions, such as reducing plastic use and monitoring waste changes through graphical representations. This indicates that mathematical learning was extended beyond calculation toward data-based environmental decision-making.

These findings support (Baptista et al., 2025), who emphasized learning to act through investigation of local environmental problems, (Karakuyu & Karafil, 2026), who demonstrated the influence of recycling-based STEM education on sustainable behavior, and (Keum & Baek, 2025), who highlighted the development of environmental competencies through STEAM programs. Thus, STEAM-based Eco-Green Mathematics learning provides opportunities for students to develop not only mathematical abilities but also environmental responsibility.

The integration of quantitative and qualitative findings suggests that the improvement of Environmental Mathematical Literacy was not only reflected in students' statistical achievement but also in their ability to apply mathematics to environmental decision-making. This finding is consistent with the explanatory sequential principle of mixed methods research, in which qualitative findings provide deeper explanations of quantitative patterns (Christodoulou, 2025). The observed findings can be understood as the result of integrating ecological contexts, mathematical reasoning, interdisciplinary activities, and action-oriented learning experiences.

Furthermore, this finding supports (Borromeo Ferri & Bulut, 2026), who emphasized the role of mathematics education in supporting education for sustainable development. The results are also aligned with (Djam'an, 2025), who highlighted the potential of integrating environmental education through STEAM approaches to develop sustainability understanding. Similar findings were reported by (Purnamasari et al., 2026) regarding the integration of green economy and numeracy in mathematics learning, and (Hemeda, 2026) regarding green mathematics innovation in secondary mathematics curricula. In addition, the connection between mathematical activities and climate-related actions supports previous findings on STEAM project learning for climate change literacy and SDG 13 action (Lestari et al., 2026), climate literacy development through STEAM collaboration (Azizah et al., 2026), and sustainability competency development through mathematics activities related to SDGs (Azizah et al., 2026).

Overall, this study provides insights into mathematics education by indicating that STEAM-based Eco-Green Mathematics learning may support the development of Environmental Mathematical Literacy through authentic environmental contexts, mathematical modeling, and interdisciplinary problem-solving activities. However, differences among students' achievement levels indicate that continuous scaffolding and differentiated support are needed to help students with different ability levels develop their abilities to formulate, employ, interpret, and take environmental actions based on mathematical reasoning.

4. CONCLUSIONS AND SUGGESTIONS

The findings suggest that STEAM-based Eco-Green Mathematics learning may support the development of Environmental Mathematical Literacy (EML) among MTs students within the context of the participating school. The quantitative results indicated that students who participated in STEAM-based Eco-Green Mathematics learning obtained higher Environmental Mathematical Literacy scores compared with students who received conventional mathematics learning. The difference was statistically significant, and the effect size analysis using Cohen's *d* indicated a large effect, suggesting a meaningful difference

between the experimental and control classes within the research context. The qualitative findings further explained that students were able to connect environmental issues with mathematical representations through problem formulation, mathematical modeling, interpretation of results, and environmental decision-making. These findings suggest that integrating environmental contexts, mathematical concepts, and STEAM activities may provide meaningful opportunities for students to apply mathematics in real-life situations while developing sustainability awareness. However, the findings should be interpreted within the limitations of this study, as the research involved a limited number of participants from one MTs setting and was conducted within a relatively short learning duration.

For educational practice, mathematics teachers may consider integrating relevant environmental issues into mathematics learning activities and providing gradual scaffolding to support students with different levels of mathematical readiness, particularly in mathematical modeling and interpretation processes. Schools may also support the implementation of STEAM-based Eco-Green Mathematics learning by providing contextual learning resources, environmental data, and project-based learning opportunities. Future research is suggested to involve larger samples from diverse school contexts, longer learning periods, and various mathematical topics to further examine the potential contribution of STEAM-based Eco-Green Mathematics learning. Further studies may also investigate the development of each Environmental Mathematical Literacy indicator in greater depth, as well as its relationship with students' environmental attitudes, sustainability competencies, and long-term problem-solving abilities.

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