

The Impact of STEM-EfSD Games on Enhancing Students' Creative Thinking and Environmental Literacy

Winarto ^{1*}, Dadan Rosana¹, Widodo Setiyo Wibowo¹, Dita Puji Rahayu¹, Pramudya Wahyu Pradana¹, Galih Albarra Shidiq²

¹ Universitas Negeri Yogyakarta, INDONESIA

² Chulalongkorn University, THAILAND

*Corresponding Author: winarto88@uny.ac.id

Citation: Winarto, Rosana, D., Wibowo, W.S., Rahayu, D.P., Pradana, P.W., & Shidiq, G.A. (2025). The Impact of STEM-EfSD Games on Enhancing Students' Creative Thinking and Environmental Literacy. *European Journal of STEM Education*, 10(1), 23. <https://doi.org/10.20897/ejsteme/17354>

Published: November 2, 2025

ABSTRACT

The issue of environmental pollution in urban areas is becoming more prevalent. Students require the implementation of environmental education. The purpose of this study is to analyze the impact of STEM-EfSD games on improving creative thinking and environmental literacy. We employed a quasi-experimental one-group pretest-posttest design as the research method. One class consisted of 32 grade 7 students from the Yogyakarta school who participated in this study. The study employed creative thinking tests and environmental literacy questionnaires as data collection techniques, along with data analysis methods such as the paired t-test, Wilcoxon test, and effect size analysis. The results of the Wilcoxon analysis for creative thinking ability show a p-value of <0.001 , which is certainly <0.05 . This indicates a significant difference in the creative thinking abilities of students before and after the intervention with game-based STEM-EfSD learning. In a manner akin to creative thinking skills (Suryani et al., 2025), the paired sample t-test analysis of environmental literacy data revealed a p-value of 0.013, which is less than 0.05. This indicates a significant difference in the measurement results before and after the learning process. This study revealed variations in creative thinking and environmental literacy among students who engaged with games compared to those who did not. The findings of this study indicate that STEM-EfSD game media enhances students' creative thinking and environmental literacy skills. The skills developed here influence the environmental education within the school system by incorporating games that leverage the insights from this study.

Keywords: STEM-EfSD, Games based-learning, Creative thinking, Environmental literacy

INTRODUCTION

Creative thinking is crucial for equipping students to face intricate and ever-changing challenges ahead. Creative thinking encompasses the ability to come up with original ideas, tackle challenges in unique ways, and examine issues from various angles (Carranza, 2021; Good, 2024; Grewe, 2025). This skill serves as a significant advantage for students as they tackle more intricate problems, enhancing their productivity and fostering innovation (Gomez, 2024; Istikomah et al., 2024; Vásquez, 2021). Through innovation, productivity, and the ability to tackle diverse challenges, students can evolve into resilient individuals who thrive in the face of contemporary difficulties. Creative thinking skills are essential for students to learn in school.

In addition to creative thinking skills, environmental literacy skills are also important for students to possess amid environmental issues that will become critical challenges they will face in the future. Students with good environmental literacy skills are expected to become capable of solving environmental problems (Ozgurler & Cansaran, 2014). Students who can solve environmental problems can play a crucial role in shaping a sustainable society (Aroonsrimarakot & Laiphrakpam, 2024; Fajeriadi et al., 2024). Given the important role of environmental literacy, teaching environmental literacy to students is crucial for addressing the challenges of life.

Although creative thinking and environmental literacy are important skills to teach students, there are still many problems related to these skills in the context of learning. The findings of Heryani et al. (2023) show that many students continue to experience difficulties with their creative thinking skills. Similar findings are reported in Sugiyanto et al. (2018) and Nurdiana et al. (2020), which indicate that the achievement levels for each sub-aspect of creative thinking skills are below 50%. Additionally, the report of Meilinda et al. (2017) indicates that students' science literacy at environment-based schools remains low, with literacy achievement at 70% for each sub-aspect. The low levels of creative thinking skills and environmental literacy among students are significant issues that require prompt attention. Therefore, there is a need for interventions in learning that can effectively improve these two abilities.

Researchers have conducted various studies to address these issues. One of the most widely researched learning strategies, for example, is integrated STEM education for sustainable development (STEM-EsD or STEM EfSD). Prior investigations into STEM-EfSD have validated its efficacy in augmenting students' comprehension of socio-environmental issues (Agirreazkuenaga & Martinez, 2021), their capacity to advocate for sustainability (Olsson et al., 2022), environmental literacy (Zelenika et al., 2018), attitudes towards the environment (Aswirna et al., 2022; Zelenika et al., 2018), critical thinking competencies (Annisa et al., 2024), environmental consciousness (Annisa et al., 2024), and problem-solving abilities (Solihah et al., 2024). While earlier research has thoroughly investigated how STEM-EsFD learning affects students' skills, there is a scarcity of studies examining its more profound effects on students' creative thinking and environmental literacy. Furthermore, studies on game-based STEM-EsFD learning are still scarce.

Given the limitations of previous research, we sought to investigate the impact of STEM-EfSD games on students' creative thinking and environmental literacy skills. The purpose of this study was to determine the impact of STEM-EfSD games on improving students' creative thinking and environmental literacy skills. To answer this research question, we conducted a quasi-experimental study comparing the impact of learning with STEM-EfSD games and without STEM-EfSD games. This study is expected to provide new insights into the impact of STEM-EfSD games in science education.

Theoretical framework

EfSD based Games Contribution: Optimizing Creative Thinking and Environmental Literacy

Creative thinking involves the capacity to come up with fresh and meaningful ideas that fit within a specific context. Creative thinking plays a crucial role in many areas, such as education, the arts, and the creative sectors. In the current digital era, games have become a vital aspect of daily life, particularly for the younger generation. Numerous recent studies have investigated the connection between gaming and the development of creative thinking skills. Numerous studies have shown that games, especially those focused on strategy, puzzles, and adventure, can improve creative thinking abilities. Research conducted by P K et al. (2023) and Bernik et al. (2023) indicates that games designed to challenge players in problem-solving can improve cognitive flexibility and divergent thinking. Alwhaibi et al. (2024) discovered that participating in games boosts players' creative problem-solving skills. Games featuring open-world or sandbox elements, like Minecraft and The Sims, provide players with the opportunity to explore and create, which can enhance imagination and creativity (Rahimi et al., 2024). Nonetheless, some studies did not yield favorable results. While games can enhance creative thinking, (Valiente-Barroso et al., 2024) pointed out that spending too much time gaming may diminish mindfulness and lead to a decrease in real-world creative thinking skills. Moreover, the genre of the game is crucial; games with violent themes or those that rely heavily on repetition might not deliver the same effect and could potentially stifle creativity. Research indicates that games have the potential to boost creative thinking, especially when they include features that promote creativity, such as problem-solving, open-ended exploration, and complex storylines. Nonetheless, this effect does not apply to everyone. It varies based on several factors, such as the kind of game, the length of play, and the unique traits of the player. Consequently, additional research is needed to investigate this dynamic more thoroughly.

Environmental literacy includes the information, attitudes, and abilities needed to understand and deal with problems in the environment. Recent studies have shown that video games can be an effective way to teach people about the environment in new and engaging ways. Numerous studies have shown that games can be a useful way to improve environmental literacy by giving people hands-on learning experiences. Rooney-Varga et al. (2020) discovered that simulation games that include environmental scenarios can help people learn more about and

become more conscious of environmental problems like climate change and how to manage natural resources. Lin et al. (2011) and Lasala Jr (2024) discovered that games incorporating aspects of challenge, competition, and environmental themes can enhance players' motivation to engage with environmental concerns. The findings of these studies indicate that games possess considerable potential for improving environmental literacy. Games can be a great way to teach people about the environment and excite them if they are made the right way.

Contribution of STEM in Optimizing Creative Thinking and Environmental Literacy

Creative thinking is a crucial skill for school and in many other areas of life. The integration of STEM (science, technology, engineering, and mathematics) has gained prominence as an innovative strategy to boost creative thinking skills, coinciding with technological growth and globalization. The following is a survey of the most recent research on the effects of STEM. The study by Susilowati et al. (2020) shows that combining STEM with an environmental context can help pupils think more creatively. Other research also shows that learning STEM and STEAM can help pupils be more creative (Aguilera & Ortiz-Revilla, 2021). Other studies show that learning using STEM approach can enhance student numeracy (Ibrahim et al., 2024), mathematical thinking (Flake & Rubin, 2024; Tashtoush et al., 2024), and cognitive performance (De Loof et al. 2022). These studies bolster the argument that STEM education, particularly when combined with environmental topics, can foster creativity. Studies have shown that STEM makes studying more interesting and helps pupils think more creatively (Elston-Short & Benwell, 2025). Recent studies show that this method has several advantages, such as linking technical knowledge to cultural context, improving critical and creative thinking skills, and preparing students to deal with problems in both local and global settings. Environmental literacy is becoming an increasingly significant part of education around the world. STEM (science, technology, engineering, and mathematics) and other innovative teaching methods have captured the attention of both academics and practitioners because they can help people learn more about the environment.

The effect of STEM integration on environmental literacy is the focus of this literature study. For a long time, STEM has been seen as a realistic way to teach students to think critically and solve problems. New studies show that students' understanding of environmental problems and technological solutions can be improved when STEM education is combined with environmental literacy. Students' environmental responsibility can be enhanced by integrating environmental studies with STEM curricula, as shown in a study by Vartanian (2024). (Widowati et al., 2021) also noted that the program successfully increased environmental literacy through STEM education contextualized with environmental concerns. To make environmental education more relevant and effective, they stressed the importance of incorporating local knowledge in the classroom. These results highlight the need to enhance science literacy and sustainability practices by combining STEM with environmental concerns.

Materials and Methods

We used a single-group pretest-posttest quasi-experimental design in this study, which involved administering treatment to one group and measuring variables at the beginning and end of treatment. This study was conducted from August to October 2024. The sampling technique used in this study was simple random sampling. The study participants consisted of 32 students in Yogyakarta. The data collection technique involved the use of tests to measure creative thinking skills and questionnaires to measure environmental literacy. [Table 1](#) and [Table 2](#) show the indicators of instruments used.

Table 1. Indicators of Creative Thinking Test Instrument

No	Creative Thinking Dimension	Indicators	Item
1	Fluency	Students can write down science concepts that can be applied as solutions (more than one idea) to solve environmental pollution problems	1
2	Flexibility	Students can write down science concepts that can be applied as solutions that are varied (different from each other) to solve environmental pollution problems	2
3	Originality	Students can write down science concepts that can be applied as innovative (new) and unique/out of the box solutions to solve environmental pollution problems	3
4	Elaboration	Students can write down science concepts that can be applied as solutions in the form of detailed descriptions to solve environmental problems	4

Table 2. Indicators of Environmental Literacy Questionnaire Instrument

No	Environmental Literacy Dimensions	Indicators
1	Knowledge	a. Environmental Knowledge
2	Values	b. Solutions to solve the problem
3	Attitudes	a. Concern to environment
4	Behavior	b. Motivation/self-efficacy

The instruments used in this study are valid and reliable. The environmental literacy assessment instrument has a validity index in the form of a Coefficient of Reproducibility (CR) and Coefficient of Scalability (CS) of 100%, indicating that the instrument is valid, while the reliability index is 0.75, indicating high reliability. The creative thinking ability test instrument has the same validity index value, but the reliability index is 0.53, indicating sufficient reliability. These validity and reliability values indicate the suitability of the instrument for use in research.

As a one-group pretest-posttest design study, this research consists of several stages. The first stage is a pretest to measure the students' initial abilities. After conducting the pretest, the next stage is the intervention. In the intervention stage, the teacher presents the problem of water pollution, and each group of students then examines it. The groups explore environmental material, and then each group plays a game to reinforce the concept. The group engages in three tiers of waste pollution games. Following the completion of the game, the group develops a water purification tool. The group then tests it through a virtual lab integrated with the game. After the intervention, the students' abilities are measured again in the posttest stage.

The pretest and posttest results were analyzed quantitatively to determine the impact of game-based STEM-EfSD learning on the variables. Paired sample t-tests and Wilcoxon tests were conducted to determine whether there was an improvement in students' abilities before and after learning. Effect size calculations (Cohen's d index and Matched Rank Biserial Correlation) were performed to determine the extent of the intervention's impact on improving students' abilities. Further descriptive analysis was conducted to determine the profile of students' abilities before and after the intervention for each ability indicator in more detail.

RESULTS AND DISCUSSIONS

In this study, game-based STEM-EfSD learning was successfully implemented. Students showed enthusiasm, were active, and engaged in interacting with the game during the learning process. Students used the game as a medium to solve environmental problems through the levels it presented. Students had the option to continue designing water filters until they successfully solved the water problem. Each group that completed the game became the winner. **Figure 1** illustrates student activities during the intervention phase. The game facilitates learning activities by developing creative thinking skills through problem-solving activities. The game educates students in environmental literacy by guiding them through the exploration of materials presented in the game and by completing game levels that assess their environmental knowledge. After students participated in the learning process, tests measured their environmental literacy and creative thinking.



Figure 1. Students' learning using Games

We obtained and analysed the data for hypothesis testing. Before conducting a hypothesis test with a paired sample t-test, a normality assumption test was first performed. **Table 3** presents the results of the normality test. EL stands for environmental literacy, while CT stands for creative thinking.

Table 3. Normality Test

			W	p
Post_EL	-	Pre_EL	0.989	0.978
Post_CT	-	Pre_CT	0.920	0.021

Based on the normality test, it can be seen that the p-value for the creative thinking variable is 0.021 or < 0.05 , indicating that the data is not normally distributed. This means that the creative thinking data cannot be further analyzed using a paired sample t-test, and the effect size cannot be calculated using Cohen's d index. Therefore, the analysis was conducted using non-parametric methods with Wilcoxon analysis and effect size analysis using Matched Rank Biserial Correlation.

The normality test for the environmental literacy variable yields a p-value of 0.978, which is greater than 0.05, indicating that the environmental literacy ability data of the students follow a normal distribution. As a result, this

data can be further analyzed using a paired sample t-test and an effect size analysis, utilizing Cohen's d index. **Table 4** presents the results of the paired sample t-test, Wilcoxon analysis, and effect size.

Table 4. Paired Sample T-Test, Wilcoxon, and Effect Size

Measure 1	Measure 2	Test	Statistic	z	df	p	Effect Size	SE Effect Size
Post_EL	- Pre_EL	Student	-2.622		31	0.013	-0.464	0.298
Post_CT	- Pre_CT	Wilcoxon	528.000	4.937		< .001	1.000	0.200

The results of the Wilcoxon analysis for creative thinking ability show a p-value of <0.001 , which is certainly <0.05 . This indicates a significant difference in the creative thinking abilities of students before and after the intervention with game-based STEM-EfSD learning. The magnitude of this difference is indicated by the effect size parameter, which is at a value of 1.0, indicating a significant effect. A positive effect size value indicates an improvement in students' abilities. This is confirmed by the increase in the average test scores for creative thinking ability, which rose from 31.7 to 82.5. The increase in the average creative thinking ability scores is presented in the graph in **Figure 2**.

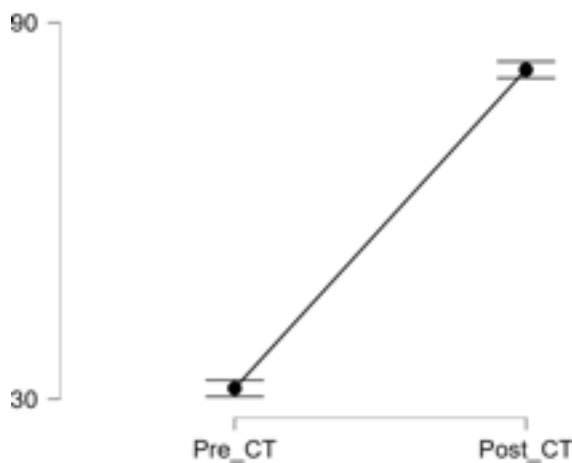


Figure 2. Graph of average final pretest and posttest scores for critical thinking skills

This significant improvement in creative thinking skills is consistent with several theories and findings from previous studies. Research by Seyediasl et al. (2021) supports the findings of this study, demonstrating significant differences in creativity between students who do not play games and those who play for up to two hours a day. Research has shown that students who engage in play for extended periods are more creative. Gackebach and Dopko (2012) state that playing games plays an important role in enhancing students' creativity. Students who often engage in gaming may have the opportunity to delve into ideas during their dreams, potentially sparking their creativity. Hui & Mahmud (2023) discovered comparable findings, showcasing the beneficial effects of game-based learning on student education. Similar findings were presented by Papadakis (2018), who noted that games can improve learning by creating a more engaging educational atmosphere. Educators noted that games are crucial in enhancing motivation within the learning environment and igniting students' passion for learning. Moreover, besides utilizing games, STEM learning applications also impact creative thinking abilities. Research conducted by Suryani et al. (2024), Khalil et al. (2023), and Rahmadani et al. (2025) demonstrates that students engaged in STEM learning exhibit superior creative thinking abilities compared to their peers who do not participate in such programs. This suggests that the STEM learning model positively impacts students' creative thinking skills. Furthermore, a study conducted by W. Anggraini et al. (2019) indicates that EfSD promotes creative thinking among students by engaging them in learning activities that improve their cognitive abilities, foster creative thinking skills, and cultivate ecological literacy through the challenges presented. The theories and findings indicate that STEM learning, games, and EfSD learning have the potential to boost creative thinking skills. The integration of these three learning components into game-based STEM-EfSD learning could clarify why STEM-EfSD learning is so effective in boosting students' creative thinking skills.

Similar to creative thinking skills, paired sample t-test analysis of environmental literacy data showed a p-value of 0.013 or < 0.05 , indicating a significant difference between the measurement results before and after learning. Although Wilcoxon test results for creative thinking skills were similar to those for the paired sample t-test for

environmental literacy, the effect size calculations showed very different results. The effect size results for environmental literacy ability show a value of -0.464. This value indicates a moderate decrease in participants' environmental literacy ability. This moderate effect is evident from the decrease in the average final score of the environmental literacy questionnaire, which dropped from 74.0 to 69.97 after the intervention. This decline is illustrated in the graph shown in [Figure 3](#).

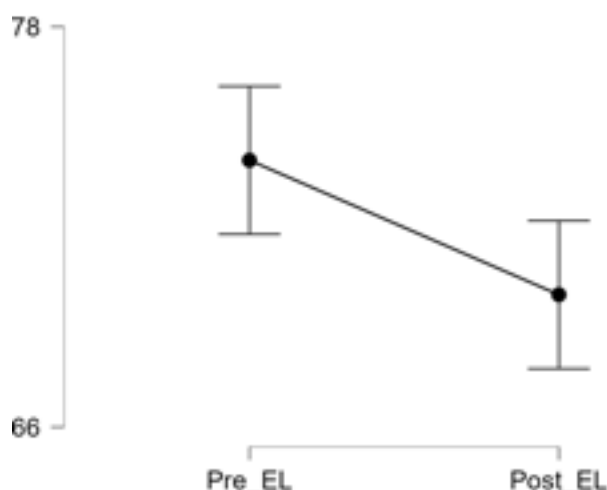


Figure 3. Graph of average final pretest and posttest scores for environmental literacy

The significant difference in environmental literacy skills is consistent with several existing theories and studies. However, the negative effect size results, which indicate a decline in environmental literacy skills, contradict previous theories and studies. For example, Anggraini et al. (2022) research demonstrates that the implementation of STEM learning has an impact on environmental literacy. Students in Yogyakarta City have become accustomed to coexisting with the environment, exhibiting greater sensitivity to environmental conditions, and successfully addressing numerous environmental challenges. Research by Tan & Nurul - Asna (2023) indicates that games have a significant impact on environmental literacy. Finally, W. Anggraini et al. (2019) research states that EfSD can help improve ecological literacy or environmental literacy. These findings and theories have separately shown that STEM learning, games, and EfSD can improve science literacy, and hypothetically, the combination of the three should effectively enhance environmental literacy.

This decline in environmental literacy is not normal. Ideally, when someone learns, the worst possible pretest and posttest results should show no difference at all. Various factors may cause this decline in science literacy, one of which is the stress experienced by students during learning or when taking assessments. This hypothesis is supported by research by Kaphle et al. (2024), which shows a correlation between stress and students' academic performance. Nevertheless, further research is needed to confirm these findings. Upon closer examination, the data on environmental literacy is not normally distributed. Therefore, research with a larger sample size and normal distribution may yield more convincing results.

In this study, we investigated the impact of game-based STEM-EfSD learning on environmental literacy and creative thinking skills. This study aims to provide new insights into methods that can effectively enhance these two skills. Further research is needed to investigate how game-based STEM-EfSD learning impacts other student skills, such as problem-solving, motivation, and student engagement in the learning process. Research on the same variables as this study, but employing different research methods, is also ongoing. Such follow-up studies are expected to provide strong and comprehensive evidence regarding the impact of game-based STEM-EfSD learning on students.

This study is limited by the small number of participants from three schools and specific grade levels. Therefore, it may not be fully generalizable to all student populations with different cultural, socioeconomic, or educational backgrounds. A larger and more diverse sample would strengthen the external validity of the results. Furthermore, the intervention was implemented over a limited period of one month. The long-term impact of the STEM-EfSD game on the retention of creative thinking skills and environmental literacy remains unknown. Longitudinal studies are needed to assess whether the observed improvements are sustained over time. This study relied on specific instruments to measure creative thinking. Although efforts were made to ensure validity and reliability, these instruments may not capture the full spectrum of this complex construct. While efforts were made to control the research environment, external factors such as students' prior knowledge, teachers' enthusiasm for delivering the intervention, and events in the broader school environment could have influenced the results, potentially confounding the findings.

CONCLUSIONS

Learning with STEM-EfSD games can significantly improve students' creative thinking skills. However, our findings indicate that STEM-EfSD may reduce students' environmental literacy skills at the intermediate level. Nevertheless, further research is needed to strengthen the findings and identify the causes of the decline in students' environmental literacy skills. These findings indicate that STEM-EfSD game-based learning not only enhances content-related knowledge but also improves higher-order thinking skills, such as students' creative thinking abilities.

ACKNOWLEDGEMENTS

Thank you for Universitas Negeri Yogyakarta funded this research in 2024 under the structural lecturer and professor assignment grant scheme. This article was funded by the World Class University Program-State University Management Body with Legal Entity (WCU-BPPTNBH) of Yogyakarta State University in 2025.

CONFLICT OF INTERESTS

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Winarto and Dadan Rosana constructing and reviewing the literature. Widodo reviewed the literature and edited the manuscript by Dita, Pramudya and Galih. All authors read and approve the final manuscript.

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