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Enhancing Students' Critical Mathematical Thinking in Algebra through STEAM-Based Flood Simulation and Mitigation Projects

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ABSTRACT

The students' critical mathematical thinking remains a major challenge in mathematics education in Indonesia, as reflected in the low rankings in TIMSS and PISA. This study aims to analyze the effect of implementing STEAM-based project learning through flood simulation and mitigation projects on students' critical mathematical thinking in algebra. These dual challenges highlight the urgent need for innovative educational approaches that not only address academic deficiencies but also connect students to real-world problems. In response to this, the study explores the integration of Science, Technology, Engineering, Arts, and Mathematics (STEAM) within a Project-Based Learning (PjBL) framework—specifically applied to algebra content related to flood mitigation. The main method employed is a quantitative experimental design, involving a sample of 60 seventh-grade students from two different classes at SMPN 39 Semarang, selected purposively. The primary instruments include posttest assessments designed to measure critical thinking. Data collection involved administering the tests and observing the learning process, with analysis conducted using t-tests to compare the mean scores of the experimental and control groups. Results indicated that students in the experimental group significantly outperformed those in the control group in post-test scores. The novelty of this research lies in integrating flood mitigation projects within the STEAM framework specifically to enhance critical thinking in algebra. The findings suggest that STEAM-based learning models can serve as an effective strategy to enhance 21st-century competencies in mathematics education, particularly in content related to environmental and social challenges.

Keywords: Critical Mathematical Thinkimg; Flood Simulation; Mitigation; Project-based Learning; STEAM

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Introduction

Floods cause significant damage across the Asian region each year (Abbas et al., 2016), including in Indonesia, which frequently experiences severe flooding. To reduce the risks faced by communities in disaster-prone areas, proactive mitigation efforts are essential (Ningrum & Ginting, 2020). This highlights the urgent need to address disaster mitigation, particularly in the context of flood preparedness. In this regard, the STEAM (Science, Technology, Engineering, Art, and Mathematics) approach has been identified as a suitable educational strategy that integrates scientific principles into learning (Belbase et al., 2022; Mu'minah, 2021). Rather than being merely a teaching methodology, STEAM can be positioned as a holistic strategy for organizing and responding to real-world problems (Roldán-Zafra & Perea, 2022). It provides a structured framework for engaging with complex materials and challenges (Mei et al., 2023;

Pramasdyahsari et al., 2023; Thuneberg et al., 2017). Complementing this, the Project-Based Learning (PjBL) model has also been shown to effectively enhance students' critical thinking skills (Pramasdyahsari et al., 2023)(Astutik et al., 2024; Pramasdyahsari et al., 2023; Pramasdyasari et al., 2024) (Aldabbus, 2018; PjBL emphasizes active student involvement in problem-solving and is specifically designed to engage learners with complex, real-life issues that require investigation and collaborative solution-building (Pramasdyahsari et al., 2025).

By combining science, technology, engineering, arts, and mathematics and using the Pjbl model in the context of disaster mitigation, students can develop a comprehensive understanding of the complexity of the challenges faced and design effective and sustainable solutions with a project (Pramasdyahsari et al., 2024; Barron et al., 1998) . The era of openness is proven by the development of science and technology, this era is called the 21st century which emphasizes or demands more in creating quality human resources, especially in the world of education (Hasibuan & Prastowo, 2019 ; Rosnaeni, 2021) . Education is the essence of advancing a nation, for that learning must focus on 21st century skills. Learning must be designed according to the 4C skills which include, 1) critical thinking skills, 2) creative and innovative thinking skills, 3) communication skills, 4) collaboration (Zubaidah, 2018) . Of the four skills, critical thinking is one of the crucial aspects that every student must have because it is the basic capital or intellectual capital in a systematic deductive way of thinking in assessing or evaluating, and making decisions or solving problems (Setiana et al., 2021; Brashear et al., 1995; Miatun & Husna, 2020). Critical thinking skills are needed in analyzing, evaluating, and making decisions or reasons appropriately for a complex problem (Janah et al., 2019) . National Education Regulation Number 22 of 2017 (BNSP, 2017) emphasizes that critical thinking skills are needed so that students can manage and utilize information.

Although critical thinking skills are important for every student, the mathematical critical thinking skills of junior high school students in Indonesia are still relatively low. Even at the international level. This is based on the 2011 TIMSS study, Indonesia was ranked 38th out of 42 participating countries with an average of 386. A similar condition can be seen from the results of a study conducted by PISA (Program for International Student Assessment). The results of the 2012 PISA study, Indonesia was ranked 64th out of 65 participating countries with an average score of 375, while the international average score was 500 (OECD, 2012) . Studies conducted by TIMSS and PISA show that Indonesia's scores are still below the international average. In the research results (Anisa et al., 2021; Wahyuni & Kusaeri, 2024) also showed that the results of students' critical thinking skills in Indonesia are still low.

In the 21st century, students are emphasized to have critical thinking skills in dealing with real-life problems, as well as in the student-centered mathematics learning process in collaboration (Grant et al., 2015; Syarlisjiswan et al., 2021) . Mathematics is one of the basic materials given to all students starting from elementary school and a discipline that plays an important role in human life (Tashtoush et al., 2022) . However, mathematics is still considered difficult and boring (Dewi et al., 2020) . One of them is in the Algebra material which is an important milestone but has a fairly high level of difficulty and is considered abstract by students (Rahayu et al., 2022; Star et al., 2015) . Therefore, it is necessary to provide a STEAM-based learning concept as a development of an integrative approach in the teaching and learning process and help them understand several complex concepts related to algebra (Izquierdo et al., 2016) .

Although previous studies have highlighted the benefits of STEAM-based Project-Based Learning (PjBL) in fostering critical thinking and engagement across various subjects, limited research has specifically examined how mathematical concepts particularly algebra can be integrated with real-world environmental issues like flood mitigation within a full STEAM framework (Supianti et al., 2025). Theoretically, there is a gap in understanding how contextualized, interdisciplinary learning models impact students' critical mathematical thinking, especially when addressing complex socio-environmental problems. Methodologically, few studies in the Indonesian context have employed rigorous experimental designs to measure the effectiveness of such integrated models. This research seeks to fill both gaps by designing and testing a STEAM-oriented PjBL model that embeds algebra learning in the context of flood simulation and mitigation. The urgency of this study stems from the dual need to improve students' higher-order thinking skills in mathematics and to make learning more relevant by connecting it to pressing local and global challenges such as climate-induced disasters.

Methods

The approach used in this study is a quantitative approach, starting from data collection to analysis. Quantitative research is considered a deductive approach to research (Soegiyono, 2011 ; Almalki, 2016; Creswell, 2015) . The researcher used a posttest-only control group design approach.

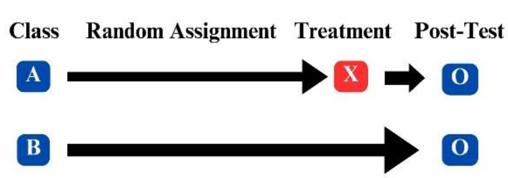


Figure 1. *Research Design*

Where the researcher gave a post-test to the control and experimental groups and only the experimental group received treatment to evaluate the effect of STEAM learning on flood disaster mitigation through the *flood simulation and mitigation project* on students' critical thinking skills. The research was conducted through several stages, including observation at the school where the data was collected. Continued by preparing learning instruments and then validating the instruments. The next stage is to conduct research and then analyze the data obtained.

The population in this study were all students of class VII of SMPN 39 Semarang totaling 285 people in 9 classes. The sample was selected using a purposive sampling technique which is also called deliberate sampling based on assessment because of the quality possessed (Etikan, 2016) . The research sample consisted of class VII-H with 30 students as a control class using a direct learning model and class VII-I with 30 students as an experimental class that received STEAM mitigation-based project learning treatment.

At the stage of quantitative data collection in this study, the instrument used was a post-test to measure student learning outcomes using the flood simulation and mitigation project. The critical thinking abilities of students were evaluated using post-test essay questions that had been previously validated by professionals and assessed for readability. Once the research data was gathered, analyses were performed to examine the findings.

The data analysis employed experimental research, specifically a posttest-only design with groups that were not equivalent. To assess the significant differences between the control group and the experimental group, an independent t-test was conducted after fulfilling prerequisite tests, which included checks for normality and homogeneity. This particular test was aimed at determining whether there were significant differences between the students who received the intervention and those who did not. The findings from this research were analyzed using SPSS 26, with the significance level established at $\alpha = 0.05$.

Results and Discussion

Following the implementation of learning through the STEAM approach using a flood simulation and mitigation project, a post-test was administered to assess students' critical thinking skills. The post-test was designed based on six critical thinking indicators proposed by (Ennis, 2015) namely: focus, reason, inference, situation, clarity, and overview. In addition, the test items were aligned with the steps of the Engineering Design Process (EDP), particularly the phases of defining the problem and planning solutions. Prior to being administered to students, the test instrument underwent a readability assessment to ensure that the language and content were appropriate and understandable for the targeted student group.

Table 1. *Critical Mathematical Thinking Post-test Questions*

No.	Question Item
	If a miniature pool retention made own length 10 cm, width 6 cm, and height 3 cm. Calculate it. amount miniature pool Retention Required if the water is collected is 1,080 cm^3. a. Based on the reading above do you agree if the problems presented is loss consequence flood ? Give the reason . b. Write it down form algebra for determine the volume of the container c. In your opinion, is the maximum capacity of the container an essential factor in designing a mini swimming pool capable of holding water? What is the required capacity of the container to ensure that the miniature retention pond can adequately hold water? d. Among the various alternative solutions, which one is the most appropriate for addressing the problem described above? Please explain the rationale behind your choice.

In the experimental class, students design a flood simulation and mitigation project to measure critical thinking skills. Students can find solutions when designing projects using miniature retention ponds of different sizes and water in bottles as a simulation of rainwater in solving contextual problems in the post-test questions given.

***Figure 2**. Design a Flood Simulation and Mitigation Project*

After being given the post-test questions, the researcher conducted a t-test to determine the effectiveness of the learning model with the STEAM approach through the flood simulation and mitigation project. Before conducting the t-test, a prerequisite test was first conducted, namely the normality test and the homogeneity test. The normality test statistics used were the Kolmogorov-Smirnov and Shapiro-Wilk tests using SPSS 26 with a significance level of >0.05.

Table 2. *Test of Normality*

Class	Statistics	df	Sig.	Statistics	df	Sig.
Experiment	0.106	30	0.200*	0.950	30	0.167
Control	0.135	30	0.174	0.933	30	0.058

Based on these results, it shows that the normality test in the differences between treatments in the experimental and control classes obtained significant values. In the experimental class, it has a p-value of 0.167 (p>0.05). The p-value in the control class is 0.058 (p>0.05). Both results state that H_0it is accepted and H_1rejected. Thus the results of the post-test values are normally distributed.

After conducting a normality test, a homogeneity test is needed to determine whether each data group and all values have homogeneous variance. The test statistic used is the Levelene's test using SPSS 26 with a test criterion of significance >0.05.

Table 3. *Test of Homogeneity of Variances*

Post-Test	Levene Statistics	df1	df2	Sig.
Based on Mean	2.602	1	58	0.112
Based on Median	2.469	1	58	0.122
Based on Median and with adjusted df	2.469	1	57.766	0.122
Based on Trimmed Mean	2.623	1	58	0.111

After conducting a normality test, a homogeneity test is needed to determine whether each data group and all values have homogeneous variance. The test statistic used is the Levelene's test using SPSS 26 with a test criterion of significance >0.05.

H_0: Students' critical thinking skills using STEAM-based flood simulation and mitigation project learning are not effective compared to using direct learning models.

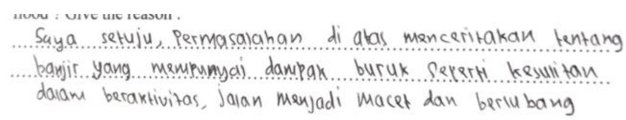
H_1: Students' critical thinking skills using STEAM-based flood simulation and mitigation project learning are more effective than using direct learning models.

Table 4. *Independent Sample t-Test*

Post-Test	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	95% Confidence Interval of the Difference Lower
Equal variances assumed	2.602	..112	8.901	58	0.000	22.633	2.543	17.544
Equal variances not assumed			8.901	53.82	0.000	22.633	2.543	17.535

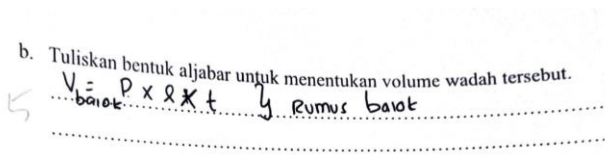
The results of the hypothesis test show that the Sig. (2-tailed) value is <0.05, so H_0it is rejected. Therefore, it can be concluded that students' critical thinking skills using STEAM-based flood simulation and mitigation project learning are more effective than using direct learning models.

This study aims to evaluate the effectiveness of a STEAM-based flood simulation and mitigation project in enhancing students' critical thinking skills. The results indicate that the project-based learning (PjBL) model is effective, as evidenced by a significant average difference in post-test scores between the experimental and control classes. When students are presented with a project that begins with a real-world problem, those with critical thinking tendencies actively seek information and collaborate with peers to better understand and complete the task. In contrast, the control group—Class VII H—was taught using a traditional, teacher-centered approach. This model limited student engagement and provided minimal opportunities for critical thinking or meaningful exploration of mathematical concepts in real-life contexts. The difference in learning approaches clearly influenced the outcomes. As shown in Figure 3 Students' answer to question 1a, Students provide reasons related to the problems given. Figure 4 Students' answer to question 1b, determine the volume of a container in algebraic form. Figure 5 Students' answer to question 1c to know required capacity of the container to ensure that the miniatur retention pool adequately hold water. Figure 6 Students' answer to question 1d need six containers to hold as much air, the experimental class, which integrated STEAM-based project learning on algebra material, demonstrated significantly better post-test results, highlighting the effectiveness of contextual, student-centered instruction in promoting higher-order thinking skills.



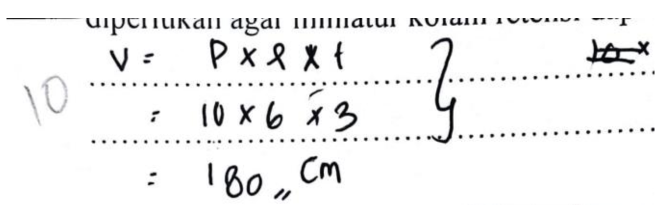
I agree, The problem above tell about floods that have disadvantages such as difficulty in carrying out activities, roads becoming congested and potholed.

***Figure 3**. Students' answer to question 1a*



$V = P \times l \times t$
(cuboid formula)

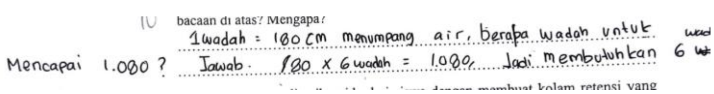
***Figure 4**. Students' answer to question 1b*



$V = P \times l \times t$
$= 10 \times 6 \times 3$
$= 180\ cm$

Thus, the capacity of the miniature retention pool to hold water is 180 cm.

***Figure 5**. Students' answer to question 1c*



The container one = 180 cm adequately hold water. how many containers to hold as much air 1.080 cm^3.

$1.080 : 180 = 6$ container.

So, need six containers.

***Figure 6**. Students' answer to question 1d*

STEAM investigates the impact of disciplinary diversity and collaboration on learning in projects (Khine, 2021) . The STEAM approach integrated through project-based learning flood simulation and mitigation improves students' skills. Therefore, it is expected that STEAM will be used more widely because STEAM-based learning significantly improves students' skills and has a positive impact on their interests (Bati et al., 2018) . This study is consistent with the results of previous studies showing that STEAM learning also has the potential to directly engage students and improve critical thinking (Mutakinati et al., 2018 ; Rusilowati, 2020) . In line with research (Cahyani & Sulastri, 2021) one innovative way to (Bugg, 1997) improve students' critical thinking skills is by using Project Based Learning with a STEAM approach. Not only critical thinking, STEAM-based project learning also stimulates skills, creates original solutions, and develops collaboration needed in the 21st century (Kubiatko & Vaculová, 2011 ; Imamah, 2020; Pasca & Waluya, 2024) . In addition, learning uses the STEAM approach through the Engineering Design Process. This is because the Engineering Design Process aims to guide students towards adaptive critical thinking to engage them in skill development (Linh & Huong, 2021) .

Achieving the quantity and quality of learning using the PjBL-STEAM model, students' critical thinking skills play an important role. In essence, students' critical thinking skills are a supporter of intellectual intelligence, because critical thinking skills influence students in decision making, project planning, and collaboration with group friends.

Conclusion

This study effectively demonstrated that implementing a flood simulation and mitigation project significantly enhances students' critical thinking skills. Quantitative data from the post-test revealed that students in the experimental group achieved higher scores compared to those in the control group, indicating the positive impact of project-based learning. Beyond fostering critical thinking, the project also supported the development of essential 21st-century competencies, including creativity, collaboration, and communication. By integrating the Engineering Design Process (EDP) within a STEAM-based learning framework, students not only gained a deeper understanding of algebraic concepts in real-world contexts but also strengthened their problem-solving abilities in addressing contextual challenges. Furthermore, the study highlights the importance of exploring strategies to utilize STEAM-based projects as a means of fostering disaster awareness and cultivating a sense of responsibility toward disaster mitigation in students.

This research offers several meaningful implications for relevant stakeholders in the field of education. For future researchers, the study provides a foundation to explore the broader implementation of the STEAM-based Project-Based Learning (PjBL) model in various subject areas and real-world issues beyond flood mitigation. It encourages further investigation into how similar models can be adapted to address other environmental or social problems, such as waste management, earthquakes, or climate change, while also examining their long-term impact on students' critical thinking and problem-solving skills. For practitioners, particularly teachers and school communities, this study demonstrates how to design and implement a learning model that integrates STEAM and PjBL approaches through contextual issues that are relevant to students' lives. By engaging students in designing flood mitigation simulations within algebra lessons, teachers can foster deeper understanding, critical awareness, and practical skills. The inclusion of digital platforms—such as Google Classroom, Geogebra, and interactive e-modules—further supports dynamic, technology-enhanced learning environments. Meanwhile, for policymakers and school administrators, the findings emphasize the importance of promoting innovative, interdisciplinary education aligned with 21st-century learning goals and the Sustainable Development Goals (SDGs). The success of this model in improving students' critical thinking skills highlights the need for policy support in providing teacher training, curricular flexibility, and infrastructure that enables contextual, culturally grounded, and technology-driven education. Especially in disaster-prone areas, such models could be embedded within school disaster education initiatives, ensuring that education not only enhances cognitive skills but also prepares students to become resilient and proactive members of their communities.

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