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THE EFFECT OF STEM-BASED MATHEMATICS LEARNING ON STUDENTS' CRITICAL AND CREATIVE THINKING SKILLS AT SMA IT YARSI MATARAM

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Abstract: *This study aims to: (1) explain the significant effect of STEM-based mathematics learning on students' critical thinking skills; (2) explain the significant effect of STEM-based mathematics learning on students' creative thinking skills; and (3) explain the significant effect of STEM-based mathematics learning on students' critical and creative thinking skills at SMA IT Yarsi Mataram. The research employed a quantitative approach with a survey research design, which was selected to obtain systematic and structured data regarding students' characteristics. The study was conducted at SMA IT Yarsi Mataram, with the population consisting of all eleventh-grade students, while the research sample comprised 53 students. The data collection instrument was a questionnaire distributed manually. The collected data were analyzed using multivariate regression analysis. The results indicate that: (1) STEM-based mathematics learning does not have a significant effect on students' critical thinking skills, as shown by a univariate test significance value of 0.971, which is greater than the 0.05 significance level; (2) the STEM approach does not have a significant effect on students' creative thinking skills, with a univariate test significance value of 0.147, exceeding 0.05; and (3) STEM-based mathematics learning does not show a significant effect on students' critical and creative thinking skills simultaneously, as indicated by a Wilks' Lambda significance value of 0.276, greater than 0.05. The implications of this study suggest that STEM-based mathematics learning cannot yet be considered an effective alternative learning strategy for developing higher-order thinking skills, particularly critical and creative thinking, highlighting the need for further research to explore learning models better suited to the characteristics of high school students.*

Keywords: *Creative Thinking, Critical Thinking, STEM-Based Mathematics Learning.*

INTRODUCTION

Education is essentially directed toward improving the quality of human resources through the learning process. Learning is designed to realize the goals of national education. According to Law Number 20 of 2003, the national education goals aim to develop learners' potential so that they become individuals who are faithful, pious, morally upright, healthy, and knowledgeable. These national objectives are further elaborated into specific learning goals, one of which is mathematics education. Mathematics learning seeks to assist students in understanding mathematical concepts, developing logical and analytical thinking skills, and applying mathematical knowledge in everyday life (Hayati & Jannah, 2024). The approaches used in mathematics learning can vary, such as exploratory approaches, problem-solving approaches, and the use of teaching aids or technology to facilitate understanding (Gusmana et al., 2025).

Mathematics learning often faces various challenges, such as a lack of conceptual understanding, minimal connection to real-world contexts, low student motivation, and less interactive teaching methods. Many students tend to memorize formulas without truly understanding the underlying concepts, which makes it difficult for them to apply mathematical knowledge in different situations. Mathematics is frequently perceived as an abstract and difficult subject, resulting in reduced student motivation to learn (Habibie, 2025). As a solution, the STEM (Science, Technology, Engineering, and Mathematics) approach can be applied in mathematics learning. Through this approach, mathematics instruction becomes more engaging, relevant, and applicable, thereby fostering improvements in students' critical and creative thinking skills.

As a solution, the STEM (Science, Technology, Engineering, and Mathematics) approach can be applied in mathematics learning. Through this approach, mathematics instruction becomes more engaging, relevant, and applicable, thereby fostering improvements in students' critical and creative thinking skills (Rendi et al., 2024). Creative thinking skills refer to the ability to generate new ideas, develop innovative solutions, and view problems from multiple perspectives. Moreover, creative thinking fosters students' curiosity and learning motivation, encouraging them to be more enthusiastic in exploring mathematical concepts in engaging and enjoyable ways (Bahasa et al., 2023).

This study examines STEM-based mathematics learning and its influence on students' critical and creative thinking skills. The significance of this research lies, first, in its contribution to improving the quality of mathematics instruction through the integration of science, technology, engineering, and mathematics (STEM), enabling students to understand concepts in a more contextual and applied manner. Second, the STEM approach is effective in stimulating students' critical and creative thinking skills, which are essential competencies for addressing the challenges of the 21st century. Third, the study provides insights for educators and policymakers in designing innovative and effective instructional strategies to enhance student learning outcomes. Fourth, it encourages students to develop independent problem-solving abilities through exploration and experimentation in mathematics learning.

Many previous studies support this research. Among the prior studies that underpin this study are, first, research findings that have shown the positive impact of STEM-based mathematics learning on improving students' critical and creative thinking skills, research Madda Salimatul Hikmah, Sugiman, dan Detalia Noriza Munahefi (2023) which explains the application of STEM in enhancing creative thinking skills. The findings indicate that STEM has a relationship with students' creative thinking, thereby improving their creative thinking abilities. This study supports the present research by demonstrating that mathematics learning with a STEM approach has an influence on students' creative thinking skills. However, the distinction from previous studies lies in the fact that this research positions STEM as a guiding framework in mathematics instruction with a quantitative research approach. Second, the research Muhamad Amin, Malik Ibrahim, dan Alkusaeri (2022) which explains the effectiveness of STEM-based learning on creative thinking skills. This study supports the effectiveness of STEM-oriented instruction and demonstrates its influence on students' creative thinking. However, what distinguishes it from the present research is that this study positions STEM as an analytical framework for examining creative thinking, while STEM is employed as an instructional method to effectively enhance students' creative thinking skills.

The implementation of STEM-based mathematics has not yet been carried out optimally, and various issues are still found that hinder the full application of the STEM approach. First, teachers' mastery of STEM concepts is not evenly distributed, as although several STEM projects have been implemented, not all teachers are likely to have a deep understanding of the integrative nature of STEM. Second, the implementation lacks consistency, since the STEM approach appears to be applied only to certain topics (such as solid geometry, probability, social arithmetic, and trigonometry), while other materials have not yet adopted it. Third, limited instructional time poses a challenge, as STEM projects generally require longer periods for exploration, experimentation, and presentation.

Initial observations conducted from April 10 to April 17, 2025, at SMA IT Yarsi Mataram revealed several findings related to mathematics learning as well as students' critical and creative thinking skills. Mathematics instruction at SMA IT Yarsi Mataram has implemented a STEM-based approach. Several forms of STEM-based mathematics learning were identified. First, mathematics learning on solid geometry topics is carried out using mathematical software technology to create three-dimensional figures that are more engaging and easier to understand. Second, learning on probability topics is implemented through project-based activities involving the creation of instructional tools to represent probability concepts. Students design and construct these tools directly based on their knowledge and interests. Third, learning social arithmetic is conducted by producing processed food products from various ingredients, such as fruits or vegetables. Students are asked to create posters, e-posters, or short videos on websites to market their products. Fourth, learning trigonometry is implemented through project-based tasks in which students calculate the angle of elevation of a building. Working in groups, students observe, measure, and analyze using different techniques.

RESEARCH METHODOLOGY

The research approach used in this study is quantitative with a survey research design. Survey research was chosen because it is able to collect systematic, structured, and objective information regarding students' attitudes, perceptions, and characteristics related to STEM-based Mathematics learning as well as critical and creative thinking skills. The research was conducted at SMA IT YARSI Mataram, with the population consisting of all eleventh-grade students. From this population, a sample of 53 students was selected as the research respondents. The research instrument used was a closed-ended questionnaire developed based on indicators of critical thinking skills, creative thinking skills, and the characteristics of STEM-based Mathematics learning. The questionnaire was distributed manually to ensure a high response rate and clarity of completion by the respondents. Before being used, the instrument was tested for validity and reliability to ensure the accuracy and consistency of the data obtained. Data analysis was carried out using multivariate regression, which aims to analyze the effect of STEM-based Mathematics learning on students' critical and creative thinking skills both simultaneously and partially. The selection of multivariate regression was based on the need to examine the causal relationships of more than one dependent variable within a comprehensive analytical model. The research design employed was an analytic design with a Cross-Sectional approach, in which data were collected at one point in time to describe the relationships among variables as a whole. This design allows the researcher to identify patterns, trends, and relationships between STEM learning and students' critical and creative thinking skills in an efficient and measurable manner.The research design employed in this study is presented in Figure 1.

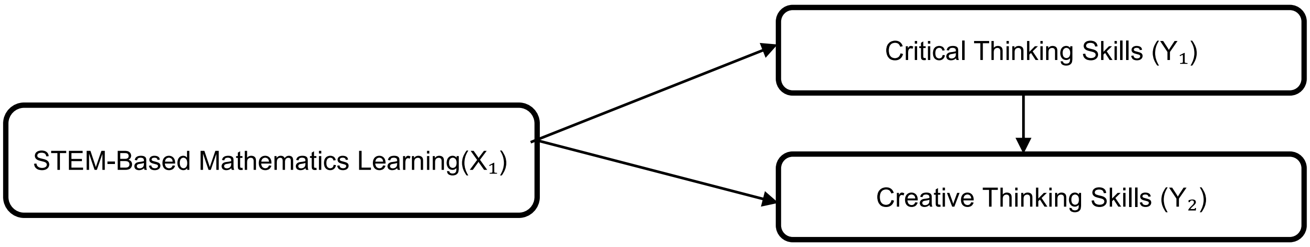

Figure 1. Model of the Relationship between the Independent Variable and Two Dependent Variables

RESULTS AND DISCUSSION

Results

This study employs multivariate regression analysis to examine the effect of STEM-based mathematics learning on students' critical and creative thinking skills at SMA IT Yarsi Mataram. Prior to testing the effects, the researcher conducted prerequisite tests, including tests of normality, multicollinearity, and the KMO and Bartlett's Test. Subsequently, simultaneous univariate and multivariate tests were performed to address the three research objectives of this study.

A. Prerequisite Tests

1. Multivariate Normality Test

The normality test of data distribution is an important step in statistical analysis to ensure that the data used in a study follows or closely approximates a normal distribution. This assumption of normality is often required for various parametric statistical analyses, such as t-tests, ANOVA, or regression analysis, because these methods rely on the properties of a normal distribution. Normally distributed data are required to produce valid statistical estimates. In this study, the multivariate normality test of the response variables was conducted using the Regression test in SPSS version 25 to examine the correlation obtained from the chi-square plot coefficient values. The criterion for normality is determined by the significance value: if the obtained significance value is greater than 0.05 (at a 5% significance level), the data are considered to be normally distributed. Conversely, if the significance value is less than 0.05 (at a 5% significance level), the data are not normally distributed. Using SPSS, the results of the multivariate normality test for the response variables were obtained and can be observed through the scatter plot in Figure 2 and the correlation table in Table 1.

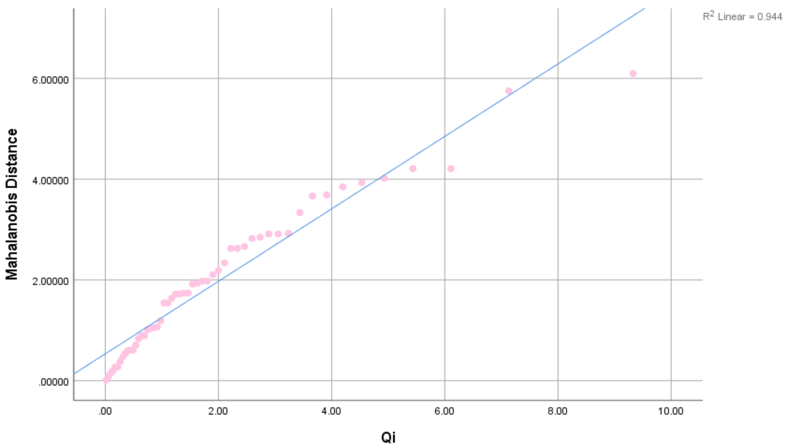

Figure 2. ***Scatter-Plot***

Next, consider the data below.

Table 1. Results of the Normality Test Based on Correlation Analysis

		MD	QI
Mahalanobis Distance	*Pearson Correlation*	1.000	0.972
	Sig	-	0.000
	N	53	53
Qi	*Pearson Correlation*	0.972	1.000

Based on the results of the normality test using the regression test, the obtained correlation coefficient of 0.972 indicates a very high correlation. The correlation coefficient ranges from −1 to +1. If the correlation coefficient is greater than the r-table value or the significance value is less than 0.05, it indicates a significant correlation. Based on the scatter plot and the table, these results indicate that the data originate from a sample that follows a multivariate normal distribution.

2. Multicollinearity Diagnostic Test

Multicollinearity can be detected using the Variance Inflation Factor (VIF) and tolerance values. A VIF value greater than 10 indicates high multicollinearity, while a tolerance value of less than 0.1 also suggests the presence of multicollinearity. Therefore, for the research data to be free from multicollinearity issues, the tolerance value must be greater than 0.1 and the VIF value must be less than 10. The results of the multicollinearity test in this study are presented in Table 2.

Table 2. Results of the Multicollinearity Diagnostic Test

Variable	Critical Thinking (Y1)		Creative Thinking (Y2)	
	Tolerance	VIF	Tolerance	VIF
STEM-Based Mathematics Learning (X1)	1.000	1.000	1.000	1.000

Based on Table 2. the STEM-based mathematics learning variable (X1) in relation to critical thinking skills (Y1) and creative thinking skills (Y2) shows a tolerance value of 1.000, which is greater than 0.10, and a VIF value of 1.000, which is less than 10. This indicates that there is no multicollinearity issue in the relationship between the STEM-based mathematics learning variable and students' critical and creative thinking skills. Therefore, it can be concluded that the regression model used in this study meets the assumption of multicollinearity, indicating that the independent variable is suitable for testing its effect on the dependent variable.

3. Test of Independence Among Response Variables

The test of independence among response variables aims to examine whether the response variables in a statistical model are independent of one another. In multivariate analysis, response variables are those influenced by other variables, such as in multivariate regression or analysis of variance. To ensure valid analytical results, it is often assumed that these response variables are mutually independent. Several methods are used to test this independence, including the Pearson correlation test, which measures the linear relationship between response variables, as well as independence tests such as the chi-square test for categorical data. In addition, in multivariate analysis, correlation or covariance matrices are used to assess the extent to which response variables are related to one another, where a matrix determinant close to zero indicates dependence among variables. Wilks' Lambda test is also commonly applied in MANOVA to examine the independence among response variables. If the test results indicate a significant relationship, it means that the variables are not independent of each other. This test of independence among response variables is crucial to ensure that the basic assumptions of multivariate analysis are met, allowing the analytical results to be interpreted correctly. The results of the test of independence among response variables in this study are presented in Table 3.

Table 3. Results of the Independence Test Among Response Variables

Bartlett's Test of Sphericity	Approx. Chi-Square	9.460
	Df	1.000
	Sig	0.022

Based on Table 3, significance value or P-Value is 0.022, meaning that the P-Value < α at $\alpha = 5\%$. This indicates that the response (dependent) variables are independent of each other.

4. Multivariate Regression Parameter Estimation Test

Table 4 presents the results of multivariate regression parameter estimation, which were used to analyze the effects of critical and creative thinking skills.

Table 4. Results of Parameter Estimation Using Multivariate Regression Methods

Variable	Unstandardized Coefficient B	*t*	Sig
Critical thinking	0.002	0.037	0.971
Creative thinking	-0.082	-1.472	0.147

Table 4 presents the results of regression analysis, which include the columns Unstandardized Coefficients (B), t-values, and significance values (Sig.). The Unstandardized Coefficients (B) column indicates the magnitude of the regression coefficient for each variable, representing the average change in the dependent variable for every one-unit increase in the independent variable, assuming other independent variables remain constant. The t column shows the test statistic used to examine the significance of each regression coefficient, while the Sig. The column presents the probability value (p-value) associated with the test.

Based on Table 4, regression analysis was conducted on two variables, namely critical thinking and creative thinking, considering the regression coefficient (Unstandardized Coefficient B), t-statistic, and significance level (p-value). The critical thinking variable has a regression coefficient of 0.002, with a t-value of 0.037 and a significance level of 0.971. This significance value is much greater than the 0.05 significance level, indicating that critical thinking does not have a significant effect on the dependent variable. The positive regression coefficient indicates a positive direction of the relationship; however, since the effect is not statistically significant, an increase of one unit in critical thinking skills cannot be confidently demonstrated to increase the dependent variable, assuming all other variables remain constant.

Meanwhile, the creative thinking variable shows a regression coefficient of −0.082, with a t-value of −1.472 and a significance level of 0.147. This significance value is greater than 0.05, indicating that creative thinking also does not have a significant effect on the dependent variable. The negative regression coefficient suggests a tendency toward an inverse relationship, where an increase of one unit in creative thinking ability is associated with a decrease of 0.082 units in the dependent variable.

B. Hypothesis Testing

1. Simultaneous Significance Testing of Parameters

a) Simultaneous Multivariate Test

Table 5. presents the results of the simultaneous testing conducted to determine whether all parameters in the model are significant overall. The test employed is Wilks' Lambda test, as shown in Table 5.

Table 5. Simultaneous Multivariate Significance Testing

Effect Intercept	Value	F	Hypothesis df	Error df	Sig
Pillai's Trace	0.050	1.323^a	2.000	50.000	0.276
Wilks' Lambda	0.950	1.323^a	2.000	50.000	0.276
Hotelling's Trace	0.053	1.323^a	2.000	50.000	0.276
Roy's Largest Root	0.053	1.323^a	2.000	50.000	0.275

Based on Table 4, the Wilks' Lambda value was 0.950 with a p-value of 0.276. This significance value is greater than the significance level of α = 0.05, indicating that p-value > α. This result shows that, simultaneously, the independent variables tested do not have a significant effect on the dependent variables, which consist of critical thinking and creative thinking. These findings are reinforced by other multivariate indicators, namely Pillai's Trace (0.050; Sig. = 0.276), Hotelling's Trace (0.053; Sig. = 0.276), and Roy's Largest Root (0.053; Sig. = 0.276), all of which have significance values above 0.05. Therefore, it can be concluded overall that the tested model does not show a significant simultaneous effect on students' critical and creative thinking skills.

b) Simultaneous Univariate Test

Table 6. Simultaneous Univariate Significance Testing

Dependent Variable	Sum of Squars	df	Mean Square	F	Sig
Critical thinking	0.025	1	0.025	0.001	0.971
creative thinking	32.993	1	32.993	2.168	0.147
Critical thinking	951.258	51	18.652		
creative thinking	776.177	51	15.219		

Based on Table 6. the results of the univariate significance test for the dependent variables of critical thinking and creative thinking are obtained. The analysis shows that the critical thinking variable has an F value of 0.001 with a significance value (Sig.) of 0.971, which is greater than the 0.05 significance level. This indicates that there is no statistically significant difference; therefore, it can be concluded that critical thinking skills are not significantly influenced by the factors tested in the model. Furthermore, the creative thinking variable has an F value of 2.168 with a significance value (Sig.) of 0.147, which is also greater than 0.05. Thus, there is no statistically significant difference, indicating that creative thinking skills are also not significantly influenced by the factors tested in this research model.

2. Partial Significance Testing of Parameters

a) Multivariate Parameter Significance Testing

Table 7. Simultaneous Multivariate Significance Testing

Variable	Efek intercept	Multivariat Test				
		Value	F	Hypothesis df	Error df	Sig.
	Pillai's Trace	0.886	193.412[b]	2.000	50.000	0.000
	Wilks' Lambda	0.114	193.412[b]	2.000	50.000	0.000
	Hotelling's Trace	7.736	193.412[b]	2.000	50.000	0.000
	Roy's Larget Root	7.736	193.412[b]	2.000	50.000	0.000
STEM Learning	Pillais Trace	0.050	1.323[b]	2.000	50.000	0.276
	Wilks' Lambda	0.950	1.323[b]	2.000	50.000	0.276
	Hotelling's Trace	0.053	1.323[b]	2.000	50.000	0.276
	Roy's Largest Root	0.053	1.323[b]	2.000	50.000	0.276

Multivariate simultaneous significance testing in this study was conducted using multivariate statistics, including Pillai's Trace, Wilks' Lambda, Hotelling's Trace, and Roy's Largest Root. These statistics are used to assess whether the independent variables simultaneously have a significant effect on the dependent variables. Conceptually, multivariate testing aims to examine the ability of independent variables to explain the variation of multiple dependent variables jointly. In this analysis, data processing was carried out using SPSS, resulting in F-statistic values, hypothesis, and error degrees of freedom, and significance values (Sig.) as the basis for decision making.

Based on the results presented in Table 6, multivariate analysis was conducted to determine the simultaneous effect of STEM learning on the dependent variables of critical thinking and creative thinking. The multivariate test results show that for the intercept effect, the values of Pillai's Trace, Wilks' Lambda, Hotelling's Trace, and Roy's Largest Root are 0.886, 0.114, 7.736, and 7.736, respectively. All four multivariate statistics yield an F value of 193.412 with a significance value of 0.000, which is less than 0.05. This indicates that, simultaneously, there are statistically significant differences in the critical thinking and creative thinking variables when viewed from the intercept effect. Furthermore, for the effect of STEM learning, the values of Pillai's Trace, Wilks' Lambda, Hotelling's Trace, and Roy's Largest Root are 0.050, 0.950, 0.053, and 0.053, respectively, with an F value of 1.323. All multivariate statistics produce a significance value of 0.276, which is greater than 0.05. Therefore, it can be concluded that STEM learning does not have a significant simultaneous effect on the variables of critical thinking and creative thinking.

b) Univariate Parameter Significance Testing

Table 8. Simultaneous Univariate Significance Testing

Variable	Unstandardized Coefficients B	*t*	Sig. (p- Value)
Constanta	62.056	13.328	0.000
Critical thinking	0.002	0.037	0.971
Constanta	79.840	18.984	0.000
Creative thinking	-0.082	-1.472	0.147

The analysis in Table 7 shows the effect of each independent variable on the dependent variable based on the regression coefficients (Unstandardized Coefficients B), t-values, and significance (Sig.). In the first model, the constant value of 62.056 with a t-value of 13.328 and a significance of 0.000 indicates that the baseline value of the dependent variable is statistically significant when the independent variables are zero. Furthermore, the critical thinking variable has a regression coefficient of 0.002 with a t-value of 0.037 and a significance of 0.971, which is greater than 0.05, indicating that critical thinking does not have a significant effect on the dependent variable. In the second model, the constant value of 79.840 with a t-value of 18.984 and a significance of 0.000 shows that the baseline value of the dependent variable is statistically significant. Meanwhile, the creative thinking variable has a regression coefficient of −0.082 with a t-value of −1.472 and a significance of 0.147, which is greater than 0.05, indicating that creative thinking does not have a significant effect on the dependent variable.

3. Results of Residual Assumption Testing

a) Examination of the Identical Residual Assumption

Table 9. Examination of the Identical Residual Assumption

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	0.000	1	0.000	0.000	1.000^b
	Residual	951.258	0.051	18.652		
	Total	951.258	0.052			

Critical Thinking y_1

Model		Sum of Squares	df	Mean Square	F	Sig.
2	Regression	0.000	1	0.000	0.000	1.000^b
	Residual	776.177	0.051	15.219		
	Total	776.177	0.052			

Creative Thinking y_2

In Table 9. the assumption of identical residuals is examined using the Glejser test. For the residuals of the first equation, an F value of 0.000 with a significance value (Sig.) of 1 is obtained, and for the residuals of the second equation, an F value of 0.000 with a significance value (Sig.) of 1 is obtained. This indicates that the residuals are identical.

Discussion

A. The Effect of STEM-Based Mathematics Learning on Students' Critical Thinking

The results of the study show that STEM-based Mathematics learning at SMA IT YARSI Mataram does not have a significant effect on students' critical thinking skills, with a significance value of 0.971. This finding indicates that statistically there is no causal relationship between the implementation of STEM learning and the improvement of critical thinking skills. Although theoretically the STEM approach is believed to be able to develop higher-order thinking skills, this result shows that the effectiveness of STEM is highly dependent on the quality of its implementation in the classroom. STEM learning is not merely the integration of science, technology, engineering, and mathematics, but requires meaningful integration, appropriate instructional strategies, and teacher readiness in designing cognitively challenging activities. At SMA IT YARSI Mataram, teachers have attempted to implement integrative learning through discussions, contextual problem solving, and group work; however, limitations in pedagogical readiness, facilities and infrastructure, as well as student characteristics that are not yet accustomed to project-based learning and deep reflection are suspected to be factors causing the impact of STEM not to appear significantly.

From a methodological perspective, the very high significance value ($p = 0.971$) indicates that the null hypothesis cannot be rejected, so STEM-based Mathematics learning cannot yet be stated as a main determinant in improving students' critical thinking skills. This strengthens the inferential validity of the research findings, while at the same time signaling the need for a comprehensive evaluation of the STEM learning design implemented at SMA IT YARSI Mataram. Theoretically, this finding implies that the STEM model in mathematics learning does not automatically lead to an improvement in critical thinking skills, but must be supported by appropriate pedagogical approaches, such as problem-based learning, project-based learning, and systematic cognitive scaffolding.

STEM-based Mathematics learning needs to be viewed as a learning ecosystem that requires synergy between teachers' pedagogical competence, students' readiness, support from the learning environment, and contextual instructional design. Without the support of these factors, STEM risks becoming merely a label for a teaching method without providing a real impact on the development of critical thinking skills. This finding also enriches the theoretical discussion by showing that the effectiveness of STEM is conditional rather than universal, thus opening opportunities for further research to examine mediator and moderator factors that influence the success of STEM learning in improving higher-order thinking skills among students at SMA IT YARSI Mataram.

In constructivist theory, learning is understood to occur when students actively construct knowledge through real-world experiences, collaboration, and problem-solving. This approach positions students as the primary agents of learning rather than mere recipients of information, thereby training them to analyze, evaluate, and synthesize information, which are core components of critical thinking (Azzahra, 2025). STEM-based mathematics learning is closely related to contextual learning theory, which emphasizes the connection between instructional content and real-world situations. When mathematical concepts are applied in everyday life contexts through STEM, students are encouraged to think critically in understanding, analyzing, and solving complex problems (Rahmawati et al., 2022). The STEM approach is grounded in interdisciplinary integration theory, which posits that combining multiple fields of study can enhance the quality of students' thinking. In mathematics learning, this integration trains students to examine problems from multiple perspectives, thereby making their critical thinking skills more in-depth and comprehensive (Irma et al., 2021).

Previous studies have demonstrated that STEM-based mathematics learning has a positive effect on students' critical thinking skills. Research conducted by Dewi & Margunayasa (2023) shows that the implementation of STEM-based mathematics learning significantly improves elementary school students' critical thinking skills compared to conventional instruction. Similar findings have also been reported by Sennen, E., & Supardi (2021) who concluded that the implementation of STEM can encourage students to be more active in analyzing problems, evaluating information, and drawing logical conclusions. In addition, Fadillah (2024) Through the development of STEM-based mathematics learning designs at the senior high school level, researchers found that the integration of science, technology, engineering, and mathematics is effective in training students' critical thinking skills in complex mathematical topics. Other studies by Hardiana (2025) Also, confirm that STEM-integrated problem-based learning results in higher mathematical critical thinking abilities compared to control classes. Overall, these findings strengthen the empirical evidence that STEM-based mathematics learning is an effective approach for developing students' critical thinking skills across various educational levels.

B. The Effect of STEM-Based Mathematics Learning on Students' Creative Thinking

The results of the study show that STEM-based Mathematics learning does not have a significant effect on students' creative thinking skills, as indicated by a significance value of 0.147 ($p > 0.05$). This finding confirms that statistically there is no strong causal relationship between the implementation of STEM learning and the improvement of creative thinking skills. Unlike critical thinking, which emphasizes analysis and logical reasoning, creativity focuses more on divergent thinking, generating original ideas, and finding multiple alternative solutions. Therefore, the non-significant effect of STEM on creativity indicates that the integration of STEM in the classroom has not yet fully provided space for students to explore, experiment, and innovate freely.

At SMA IT YARSI Mataram, STEM learning is mostly directed toward solving structured problems and achieving curriculum targets, so learning activities tend to be convergent and oriented toward correct answers. This condition causes students' creative potential not to develop optimally, because they are not yet accustomed to designing alternative solutions, developing products, or proposing new ideas independently. In addition, limitations in teachers' experience in designing open-ended STEM projects, limited instructional time, and inadequate supporting facilities further weaken the impact of STEM learning on students' creative thinking skills. Methodologically, the significance value of 0.147 indicates that the null hypothesis cannot be rejected, so STEM-based Mathematics learning cannot yet be stated as a main determinant in improving students' creative thinking skills. This finding provides a theoretical implication that creativity does not grow automatically through the implementation of STEM, but requires a learning design that specifically targets the development of divergent thinking, such as challenge-based learning, design thinking, and project-based learning that provide space for free exploration. Therefore, STEM learning needs to be enriched with strategies that foster creative courage, tolerance for mistakes, and a culture of innovation, so that it can truly encourage the development of students' creative thinking skills at SMA IT YARSI Mataram.

STEM-based mathematics learning supports creative problem-solving theory, which emphasizes the importance of seeking innovative solutions to complex problems. The integration of mathematics with science, technology, and engineering requires students to design, modify, and evaluate solutions flexibly, thereby further sharpening their creative thinking abilities (Tobondo, 2024). STEM-based mathematics learning supports the development of Higher Order Thinking Skills (HOTS), which include creation as the highest level in the cognitive taxonomy. Through STEM activities, students not only apply mathematical concepts but also create new models, strategies, or products, thereby enabling creative thinking skills to develop significantly (Studi et al., 2024). The STEM approach aligns with Guilford's creativity theory, which emphasizes divergent thinking abilities such as fluency, flexibility, and originality of ideas. In STEM-based mathematics learning, students are given opportunities to solve problems using various strategies and approaches, thereby encouraging the emergence of creative thinking in the problem-solving process (Angela & Rahayu, 2025). STEM-based mathematics learning is grounded in constructivist theory, which emphasizes the active construction of knowledge. Through exploration, experimentation, and idea development in interdisciplinary contexts, students are encouraged to generate new ideas and alternative solutions, thereby allowing creative thinking skills to develop optimally (Muttaqiin, 2023).

Previous studies indicate that STEM-based mathematics learning has a positive effect on students' creative thinking skills. Research conducted by Anindayati & Wahyudi (2020) concluded that the implementation of STEM-based mathematics learning can encourage students to generate diverse ideas and problem-solving strategies, thereby enhancing creative thinking ability. Furthermore, research conducted by Sari (2025) showed that the STEM approach in mathematics learning has a significant effect on students' creativity, particularly in the aspects of flexibility and originality of thinking. Similar findings have also been reported by Abdulah (2024) who stated that the use of STEM-oriented mathematics teaching materials can enhance students' ability to develop ideas, modify solutions, and creatively construct mathematical models. In addition, research conducted by Sativa & Maulidian (2025) revealed that project-based STEM learning provides broad exploratory space for students to innovate and cultivate creativity in solving contextual problems. Overall, these research findings strengthen the empirical evidence that STEM-based mathematics learning is effective in developing students' creative thinking skills across various educational levels.

C. The Effect of STEM-Based Mathematics Learning on Students' Critical and Creative Thinking

The multivariate test using Wilks' Lambda shows a significance value of 0.276 ($p > 0.05$), indicating that simultaneously STEM-based Mathematics learning has not had a significant effect on students' critical and creative thinking skills. Statistically, this finding indicates that the null hypothesis cannot be rejected, so the research model has not been able to explain a strong causal relationship between the implementation of STEM learning and the development of these two higher-order thinking skills at the same time. In other words, although STEM is conceptually designed to foster analytical ability, problem solving, and creativity, its implementation at SMA IT YARSI Mataram has not produced a measurable significant impact on students' critical and creative thinking skills.

These simultaneous results are consistent with the previous partial findings. In terms of critical thinking skills, STEM learning has not shown a meaningful effect because the learning process is still dominated by activities oriented toward mastering content and solving problems, rather than developing analysis, evaluation, and deep reflection skills. Students have not been fully trained to examine problems critically, construct data-based arguments, and evaluate various alternative solutions. Meanwhile, for creative thinking skills, STEM learning has also not made a significant contribution because opportunities for divergent thinking are still limited. Learning activities tend to be structured, convergent, and oriented toward a single correct answer, so students are less encouraged to express original ideas, design innovative products, or explore various possible solutions.

Pedagogically, this finding shows that the success of STEM is highly dependent on the quality of learning design and the readiness of the school ecosystem. The integration of STEM at SMA IT YARSI Mataram has not yet been fully supported by learning approaches that foster higher-order thinking, such as problem-based learning, project-based learning, challenge-based learning, design thinking, and systematic cognitive scaffolding. Limitations in teachers' experience in designing open projects, limited instructional time, and inadequate supporting facilities collectively weaken the effectiveness of STEM in developing students' critical and creative thinking skills. As a result, STEM is more often perceived as a variation of a teaching method rather than as a learning ecosystem that transforms students' ways of thinking.

From a theoretical perspective, these multivariate results make an important contribution by showing that the effectiveness of STEM is conditional rather than universal. STEM does not automatically improve higher-order thinking skills, but requires synergy between teachers' pedagogical competence, students' readiness, support from the learning environment, and contextual and meaningful instructional design. This finding enriches the literature by emphasizing that critical and creative thinking are complex skills that develop through planned, reflective, and sustained learning processes, not merely through the integration of four disciplines into a single instructional approach. Therefore, STEM-based Mathematics learning needs to be reconstructed as a holistic learning ecosystem that not only emphasizes content integration but also the development of students' thinking processes. Strengthening teachers' pedagogical competence, developing open-ended project-based learning designs, providing wider opportunities for exploration, and creating a classroom culture that values creativity, tolerance for mistakes, and critical reflection are key so that STEM learning can truly have a significant impact on students' critical and creative thinking skills at SMA IT YARSI Mataram.

STEM-based mathematics learning is grounded in constructivist theory, which states that knowledge is actively constructed through learning experiences (Kartika & Aroyandini, 2022). Within the STEM approach, students are directly involved in problem exploration, idea testing, and reflection on outcomes, thereby fostering the development of critical thinking through processes of analysis and evaluation, as well as creative thinking through the generation of new ideas and solutions (Irma et al., 2021). STEM learning supports Higher Order Thinking Skills theory, which positions analysis, evaluation, and creation as the primary goals of learning. In STEM-based mathematics learning, students not only understand concepts but also apply them to solve complex problems and design innovative solutions, thereby allowing critical and creative thinking skills to develop simultaneously (Siregar, 2024). According to problem-solving theory, critical and creative thinking skills develop when students are faced with challenging real-world problems. STEM-based mathematics learning presents contextual problems that require students to identify issues, analyze information, and develop multiple alternative solutions creatively (Azizah & Angelina, 2025). The STEM approach aligns with divergent thinking theory, which emphasizes the ability to generate numerous ideas, strategies, and solutions. In STEM-based mathematics learning, students are given the freedom to use various approaches to solve problems, allowing creative thinking skills such as fluency, flexibility, and originality to develop without neglecting critical thinking aspects (Lestari, 2023). Experiential learning theory states that effective learning occurs through direct experience and reflection. STEM-based mathematics learning provides project- and practice-based learning experiences that enable students to analyze processes, evaluate outcomes, and modify ideas, thereby promoting the simultaneous development of critical and creative thinking skills (Nur et al., 2025). STEM-based mathematics learning aligns with contextual learning theory, which links instructional content to real-life situations. Through this context, students are trained to think critically in understanding and evaluating problems, as well as creatively in designing relevant and applicable mathematical solutions (Azizah & Angelina, 2025).

Previous studies have provided empirical evidence that STEM-based mathematics learning positively influences students' critical and creative thinking skills. Research by Wanda (2024) shows that implementing STEM-based mathematics learning significantly enhances students' critical thinking abilities through problem analysis and logical reasoning activities. Similar findings were reported by Fatras & Fajrudin (2024), who stated that STEM-integrated problem-based learning is more effective in developing mathematical critical thinking skills compared to conventional instruction. Additionally, Davidi & Supardi (2021) revealed that STEM-based mathematics learning designs not only strengthen conceptual understanding but also train students to think critically when solving complex mathematical problems. Research by Anindayat & Wahyudi (2020) found that the STEM approach can increase students' creativity, particularly in generating various problem-solving strategies. Furthermore, Rahmawati & Nurlaelah (2022) indicated that using STEM-oriented mathematics teaching materials encourages students to develop new ideas, modify solutions, and creatively construct mathematical models. Another study by Thayban & Munandar (2025) showed that project-based STEM learning provides broad opportunities for students to explore and innovate, thereby optimally developing creative thinking skills. Overall, these previous research findings confirm that STEM-based mathematics learning is effective in developing students' critical and creative thinking skills.

CONCLUSION

Based on the results and discussion, it can be concluded that

1. STEM-based mathematics learning does not have a significant effect on students' critical thinking skills. This conclusion is based on the significance value obtained from the univariate simultaneous test, which is 0.971, greater than 0.05 (5%).
2. STEM-based mathematics learning does not have a significant effect on students' creative thinking skills. This conclusion is based on the significance value obtained from the univariate simultaneous test, which is 0.147, greater than 0.05 (5%).
3. Simultaneously, STEM-based mathematics learning is not proven to have a significant effect on students' critical and creative thinking skills. This conclusion is based on the Wilks' Lambda significance value obtained from the multivariate simultaneous test, which is 0.276, greater than 0.05 (5%).

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