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# Examining the Impact of Mathematical Critical Thinking Skills on Matrix Learning Outcomes

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## ABSTRACT

Student learning outcomes represent their understanding of subject material and serve as a benchmark for evaluating educational effectiveness. A preliminary investigation at SMA Negeri 7 Gorontalo revealed low student performance in matrix-related mathematics topics. Among various factors influencing learning success, critical thinking stands out as a key internal factor in mathematics education. This study employed a quantitative, descriptive-correlational design with an ex post facto approach. It aimed to assess the mathematical critical thinking skills of Grade XI students and to examine their relationship with learning outcomes on matrix material. Critical thinking was evaluated using four indicators: analyzing, evaluating, explaining, and concluding. Findings indicated that most students had not yet achieved an optimal level of mathematical critical thinking, with an average score of 56.34 across a sample of 50 students. Correlational analysis revealed a significant positive relationship between critical thinking skills and learning outcomes, with critical thinking accounting for 61.62% of the variance in performance. The data suggest that mathematical critical thinking skills play a substantial role in determining student success in matrix material. Given the strong correlation observed, enhancing these skills may lead to measurable improvements in learning outcomes. There is a significant and positive relationship between students' mathematical critical thinking skills and their learning outcomes in matrix material. Efforts to strengthen critical thinking could be an effective strategy to improve academic performance in mathematics.



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## 1. INTRODUCTION

Learning that focuses on developing critical thinking has become a major topic in the world of 21st-century education due to its crucial role in preparing students to face real-life challenges. Educating students to think critically means shaping them into rational, logical, and careful individuals about the information, assumptions, and arguments they receive. As stated by Ennis, critical thinking is a process of thinking that is reasonable and reflective, which aims to decide what is worthy of belief and/or action (Ennis, 2011).

In practice, according to The American Philosophical Association Delphi Research Project, critical thinking encourages individuals not only to accept information at face value, but also to analyze, evaluate, and consider various points of view (Facione & Facione, 2013). (Facione, 1990) identified six indicators of critical thinking skills, involving interpreting, analyzing, evaluating, concluding, explaining, and self-regulating. These critical thinking skills play a significant role in the effectiveness of learning, including mathematics learning (Ismail & Bempah, 2018).

Mathematics can teach someone to develop critical, logical, systematic, and fact-based thinking skills. Learning mathematics is crucial as it has often been used to solve various problems, starting from simple things like buying and selling to more complex problems. Thus, the school curriculum in Indonesia requires all students at every level of education, from elementary school to high school to study mathematics (Usman, Yahya, Bito, & Takaendengan, 2022). In the process of learning mathematics, students will encounter questions that require problem-solving skills. Problem-solving includes the skills to understand problems, transform them into mathematical models, analyze the information provided, and determine the right solution to the problems faced (Habuke, Hulukati, & Pauweni, 2022). Therefore, critical thinking is a required skill as it allows students to not only solve problems but also explore various alternative solutions to these problems

Learning outcomes are one of the terms commonly used in education to describe how well students master the material being studied. Success in learning can be measured through learning outcomes that include students' understanding, skills, and attitudes (Laknasa, Abdullah, Pauweni, Usman, & Kaluku, 2021). Bloom divides learning outcomes into three domains: cognitive, affective, and psychomotor. This paper focuses on the cognitive domain, which includes thinking skills that have been developed in the Revised Bloom's Taxonomy. This taxonomy organizes the thinking process from basic to complex levels, starting from remembering (C1), understanding (C2), applying (C3), analyzing (C4), evaluating (C5), creating (C6) (Anderson et al., 2014).

In its development, these thinking skills are grouped based on their levels into two, including low-order thinking skills (Lower Order Thinking Skills or LOTS) and high-order thinking skills (Higher Order Thinking Skills or HOTS). LOTS covers C1 to C3, while HOTS covers C4 to C6. One form of HOTS is critical thinking skills (Sterkenburg, 2024). If HOTS in Bloom's Taxonomy is synergized with critical thinking skills indicators by Facione, then the critical thinking skills indicators that can be used are analyzing, evaluating, explaining, and concluding. With these indicators, students' mathematical critical thinking skills can be described more clearly, and it is easier to identify their strengths and weaknesses at each level of thinking.

However, the reality on the ground shows something different. Various studies have shown that students struggle to optimize their critical thinking skills in solving mathematics problems (Oroh, Majid, & Mohidin, 2023). Many students are only focused on examples taught by teachers without developing their thinking skills to apply concepts previously learned to relevant situations, making them unable to apply these concepts effectively in learning situations. As a result, the learning process feels boring and difficult, a perception that is often not caused by the learning process but also by the mindset of students towards learning. In addition, learning habits that emphasize memorization without understanding the material's meaning shape students into individuals who are good at memorizing but weak in critical thinking. Although the ability to memorize is important, it would be even better if students were also good at thinking. Thinking skills are certainly needed more in solving problems than just memorizing.

A preliminary study at SMA Negeri 7 Gorontalo found that even though teachers employed various learning media and methods, students' understanding of mathematics was still below expectations. Many students have difficulty solving math problems, even on matrix material which is relatively easy and basic in mathematics. Data from the last three years showed that the average final score of students on matrix material only reached 62,63.

The difficulty in matrix material mainly lies in the inability of students to connect concepts such as multiplication, inverse, and determinants with contextual problems. This difficulty arises because students need to think more deeply to not only memorize formulas, but also to analyze and apply these concepts in relevant situations. With the increasing complexity of matrix material, critical thinking skills are needed to help students develop a deeper understanding.

For example, determining the determinant of a 2×2 matrix: $\begin{vmatrix} 2 & 1 \\ 0 & 3 \end{vmatrix}$ can be answered directly by multiplying 2 and 3 to become 6. Likewise, the determinant result $\begin{vmatrix} 5 & 0 \\ 2 & 4 \end{vmatrix}$ can be obtained by multiplying 5 and 4 to become 20. Of course, the answer is not obtained just like that. The results are actually obtained from the 2×2 matrix determinant formula: $\begin{vmatrix} a & b \\ c & d \end{vmatrix} = ad - bc$. For the numbers b and/or c are 0 such as $\begin{vmatrix} 2 & 1 \\ 0 & 3 \end{vmatrix} = (2 \times 3) - (1 \times 0) = 6 - 0 = 6$. In this way, the question can be answered by multiplying 2 and 3. This simple method cannot be easily obtained without a sharp analytical exploration of a problem. Understanding with a strong and complete foundation of thinking about a problem is a tactical step to be able to exist more.

The persistent challenge students face in solving mathematical problems effectively is often rooted in their limited ability to apply critical thinking skills. This limitation is believed to contribute significantly to the low learning outcomes observed, particularly in matrix material. Therefore, exploring the relationship between mathematical critical thinking skills and student achievement is a crucial step toward enhancing the overall quality of mathematics instruction.

Prior studies have consistently highlighted the positive role of critical thinking in improving students' engagement and academic performance. Oktaviani, Shoffa, and Kristanti (2023) emphasized that integrating critical thinking into mathematics education encourages students to participate more actively in the learning process. Similarly, research by Fachriani (2020), Saputri et al. (2020), and Sari (2022) demonstrated a significant and positive influence of critical thinking skills on students' mathematics achievement. These findings reinforce the idea that strengthening critical thinking is essential for fostering deeper understanding and improved outcomes in mathematics learning.

In line with these studies, Paul and Elder (2019) underscore the importance of critical thinking in developing a solid grasp of mathematical concepts. They argue that the ability to identify, analyze, and evaluate arguments is foundational to meaningful learning in mathematics. Building on this foundation, the present study seeks to further investigate how mathematical critical thinking skills affect student learning outcomes on matrix material, offering insights that could inform future instructional strategies and curriculum development.

## 2. METHODS

This study is a quantitative descriptive-correlational study using the *ex post facto* method. Descriptive research aims to describe the phenomena or characteristics of the object being studied, while correlational research identifies the relationship between two or more variables. The *ex post facto* method was employed because the author only observes existing conditions without intervening (Sugiyono, 2013). The purpose of this study was to describe the mathematical critical thinking skills of grade XI students at SMA Negeri 7 Gorontalo on matrix material and to see its relationship with learning outcomes. The study population consisted of all grade XI students at SMA Negeri 7 Gorontalo, totaling 101 students. Of that number, 50 students were selected as samples randomly through simple random sampling.

The data in this study include the scores obtained by students after completing the mathematical critical thinking test on the matrix material, as well as learning outcomes taken from the summative assessment scores obtained by students on the matrix TP. Data were collected through tests and document studies. Written tests in the form of essay questions were used to measure students' mathematical critical thinking skills on the matrix material, using the four -indicators as independent variables (X). Meanwhile, document studies were conducted by collecting various relevant documents, including a list of names and numbers of students, learning outcomes in the last three years as initial observations, and summative assessment scores on the matrix TP as dependent variables (Y). Students' mathematical critical thinking skills scores were calculated using the percentage analysis, as follows:

$$Percentage = \frac{Total\ Score\ Achieved}{Maximum\ Score} \times 100\%$$

The scores obtained were then interpreted to determine the level and category of students' mathematical critical thinking skills, as follows.

**Table 1**. The Level and Categorization of Mathematical Critical Thinking Skills

| **Interpretation (%)** | **Category** |
|---|---|
| $81,25 < x \leq 100$ | Very High |
| $71,50 < x \leq 81,25$ | High |
| $62,50 < x \leq 71,50$ | Moderate |
| $43,75 < x \leq 62,50$ | Low |
| $0 < x \leq 43,75$ | Very Low |

*Source: (Karim, 2015)*

Then, data analysis was continued using simple linear regression and correlation to determine the relationship between variable X and variable Y.

a. Simple Linear Regression Test

Simple linear regression was employed to determine the effect of variable X on variable Y with the equation:

$$\boldsymbol{\hat{Y} = \beta_0 + \beta_1 X}$$

Where:

$\hat{Y}$ = Dependent Variable (Matrix learning outcomes)

$X$ = Independent Variable (Mathematical critical thinking ability)

$\beta_0$ = Regression constant, indicating the value of Y when X is 0

$\beta_1$ = The regression coefficient indicates the increase or decrease in the independent variable (X) relative to changes in the dependent variable (Y). If it is positive (+), the regression line slopes upward, but if it is negative (-), the regression line slopes downward.

The values of $\beta_0$ and $\beta_1$, respectively, can be calculated using the following formulas:

$\beta_0 = \frac{(\sum Y)(\sum X^2)-(\sum X)(\sum XY)}{n\sum X^2-(\sum X)^2}$;

$\beta_1 = \frac{n\sum XY-(\sum X)(\sum Y)}{n\sum X^2-(\sum X)^2}$

Once the values of a and b were determined, a regression equation can be formulated to predict how students' mathematical critical thinking skills significantly influence their learning outcomes, tested using the F Test. The effect of X on Y is significant if $F_{count}$ is greater than $F_{table}$ at the level of $a = 0{,}05$ or 5% and the degree of freedom of the nominator $df_1 = 1$ and the degree of freedom of the denominator $df_2 = n - 2$. The $F_{count}$ value is determined using the following formula:

$$F_{count} = \frac{\boldsymbol{MS_{regression}}}{\boldsymbol{MS_{residual}}}$$

Where:

$MS_{regression}$ : Average Sum of Squares Regression

$MS_{residual}$ : Average Sum of Residual Squares

b. Test of the Relationship between X and Y

A correlation test was employed to find out the relationship:

$$r_{xy} = \frac{n(\sum XY) - (\sum X)(\sum Y)}{\sqrt{n(\sum X^2) - (\sum X)^2} \cdot \sqrt{n(\sum Y^2) - (\sum Y)^2}}$$

Where

$r_{xy}$ = Correlation coefficient of variables X and Y

$N$ = Research Sample size

$\sum XY$ = The sum of the results of multiplying the independent variable (X) by the dependent variable (Y).

$\sum X$ = Total score of independent variable (X)

$\sum Y$ = Total score of dependent variable (Y)

The following references were employed to determine the strength of the relationship between the independent variable X and the dependent variable Y.

**Table 2.** Criteria for the Strength of the Relationship between X and Y

| $r_{xy}$ Value | Interpretation |
|---|---|
| $0,80 \leq r_{xy} \leq 1,00$ | Very Strong |
| $0,60 \leq r_{xy} < 0,80$ | Strong |
| $0,40 \leq r_{xy} < 0,60$ | Moderate |
| $0,20 \leq r_{xy} < 0,40$ | Weak |
| $0,00 \leq r_{xy} < 0,20$ | Very Weak |

*Source: (Sugiyono, 2007)*

A t-test was then employed to find out the significance of the relationship between variables X and Y. The significance of the relationship between X and Y if $t_{count}$ is greater than $t_{table}$ at the level of $a = 0{,}05$ or 5% with degrees of freedom $db = n - 2$. The $t_{count}$ value is determined with the following formula:

$$t_{count} = \frac{r\sqrt{n-2}}{\sqrt{1-r^2}}$$

If the correlation coefficient is positive, then there is a positive relationship direction between X and Y; in other cases, the opposite applies (Kadir, 2010). After identifying the relationship between variables X and Y, the amount of contribution of variable X in explaining the variance of variable Y is calculated with the following determination coefficient.

$$R^2 = r_{xy}^2 \times 100\%$$

Where:

$R^2$ = Coefficient of Determination

$r_{xy}$ = Correlation Coefficient

## 3. FINDINGS AND DISCUSSION

### *3.1. Findings*

The findings of this study consisted of (1) matrix learning outcomes and (2) mathematical critical thinking skills, analyzed using statistical measures:

**Table 3.** Recapitulation of Mathematical Critical Thinking Skills and Learning Outcomes

| Variable | Data | | | | | | |
|---|---|---|---|---|---|---|---|
| | $n$ | Max Score | Min Score | Mean | Median | Mode | Standard Deviation |
| Y | 50 | 90 | 10 | 59.66 | 65.50 | 76.50 | 21.06 |
| X | 50 | 93.33 | 0 | 56.34 | 59.32 | 72.50 | 22.30 |

Explanation:
Y : Learning Outcomes
X : Mathematical Critical Thinking Skills

The level of students' mathematical critical thinking skills was calculated based on the scores obtained from the skills indicators. The scoring results are presented in the following table.

**Table 4.** Description of Mathematical Critical Thinking Skills by Indicator

| Question Items | Indicator I | Indicator II | Indicator III | Indicator IV | Total Score |
|---|---|---|---|---|---|
| **1** | 208 | 185 | 172 | 140 | **705** |
| **2** | 204 | 163 | 147 | 144 | **658** |
| **3** | 155 | 144 | 131 | 29 | **459** |
| **4** | 96 | 90 | 87 | 73 | **346** |
| **5** | 87 | 58 | 55 | 53 | **253** |
| **6** | 106 | 121 | 113 | 108 | **448** |
| **7** | 116 | 105 | 104 | 195 | **520** |
| **Total Score** | **972** | **866** | **809** | **742** | **3.389** |
| **Ideal Score** | **1.500** | **1.500** | **1.500** | **1.500** | **6.000** |
| **Percentage** | **64.80%** | **57.73%** | **53.93%** | **49.47%** | **56.48%** |

The following data represent students' mathematical critical thinking skills based on their category groupings:

**Table 5.** Description of Mathematical Critical Thinking Skills Based on Categorical Groupings

| Category | Students | Total Score | Indicator | | | |
|---|---|---|---|---|---|---|
| | | | I | II | III | IV |
| Very High | 4 | 411 | 100 | 106 | 104 | 101 |
| High | 11 | 1.023 | 277 | 262 | 241 | 243 |
| Moderate | 7 | 566 | 154 | 148 | 142 | 122 |
| Low | 16 | 1.019 | 289 | 262 | 254 | 214 |
| Very Low | 12 | 370 | 152 | 88 | 68 | 62 |

To examine the relationship between X and Y, a simple regression and correlation statistical analysis was conducted as follows:

**Table 6**. General Data of Study Findings

| $n$ | $\sum X$ | $\sum Y$ | $\sum XY$ | $\sum X^2$ | $\sum Y^2$ | $(\sum X)^2$ | $(\sum Y)^2$ |
|---|---|---|---|---|---|---|---|
| 50 | 2.070 | 3.063 | 142.701,667 | 111.991,667 | 210.261 | 4.284.900 | 9.381.969 |

From the table above, the simple regression equation can be determined, resulting in the value of the regression constant $\alpha = 18{,}602$ and the direction regression coefficient $b = 0{,}7592$. Therefore, the relationship between X and Y can be described by the regression equation of Y on X**:** $\boldsymbol{\hat{Y} = 18,602 + 0,7592X}$. Before this equation is employed, it must be ensured that it satisfies the regression linearity requirement. Based on the linearity test using the F-test, the regression line of Y on X is linear. The following regression analysis of variance table (ANOVA table) presents a summary of the results.

**Table 7**. Analysis of Variance for Regression of Y on X

| Source of Variance | Df | Sum of Squares (SS) | Mean Square (MS) | $F_{count}$ | $F_{table}$ |
|---|---|---|---|---|---|
| Total | 50 | 210.261 | - | - | - |
| Regression (a) | 1 | 187.639,38 | 187.639,38 | | |
| Regression (b/a) | 1 | 13.940,33 | 13.940,33 | 77.08 | 4.04 |
| Residuals | 48 | 8.681,29 | 180,86 | | |
| Mismatched | 36 | 6.199,62 | 172,21 | 0.83 | 2.44 |
| Error | 12 | 2.481.67 | 206.81 | | |

The next step was to test the relationship between the two variables using the correlation coefficient test. A summary of the test results for the relationship between X and Y through simple regression and correlation analysis was presented in the following table

**Table 8.** Summary of the Significance Calculation Results of the Correlation Coefficient between X and Y

| $n$ | $df$ | $r_{xy}$ | $r_{xy}^2$ | Contribution (%) | $t_{count}$ | $t_{table}$ |
|---|---|---|---|---|---|---|
| **50** | 48 | 0.7850 | 0.6162 | 61.62% | 8.78 | 2.01 |

### 3.2. *Discussion*

#### 3.2.1. Description of Student' Mathematical Critical Thinking Skill

Based on the results of the mathematical critical thinking ability test conducted in class XI at SMA Negeri 7 Gorontalo, the total score obtained was 3.389 out of 6.000 ideal scores, with an achievement percentage of 56,48%. This achievement is categorized as low according to Table 1 interpretation. The analyzing indicator recorded the highest achievement, which was 62,80%. Students could generally identify the information provided and compile appropriate mathematical models, although some still made mistakes in interpreting the information. The evaluation indicator had an achievement level of 57,73%, indicating that students had difficulty choosing the right concept or formula to solve the problem. In the explaining indicator, the achievement level reached 53,93%, indicating that most students could still not compile the steps for solving systematically and clearly. The concluding indicator recorded the lowest achievement level, which was 49,47%, because many students could not draw correct conclusions from the results of solving the problem.

Based on the category grouping, students were divided into five levels, encompassing very high, high, medium, low, and very low. This grouping was based on the students' critical mathematical thinking skills scores. The results showed that 4 students (8%) were in the very high category, with excellent critical thinking skills across all indicators, particularly in systematic analysis and explanation. A total of 11 students (22%) were included in the high category, demonstrating good skills, though with minor shortcomings in drawing conclusions or connecting analysis results with explanations. A total of 7 students (14%) were in the medium category, indicating moderate skills, but their analysis and explanations tended to be shallow, and their conclusions were often imprecise or insufficiently developed. In the low category, 16 students (32%) exhibited significant challenges, particularly in forming conclusions and providing coherent explanations, although they could identify basic information in their analysis. Meanwhile, 12 students (24%) were in the very low category, with substantial weaknesses in all aspects of critical thinking, especially in understanding, analyzing, and formulating logical explanations or conclusions. These results emphasize the need to enhance students' critical mathematical thinking abilities, particularly in the indicators of evaluating, explaining, and concluding.

### 3.2.2. Mathematical Critical Thinking Ability on Learning Outcomes

The results indicated that the relationship between mathematical critical thinking skills (X) and learning outcomes (Y) can be described by the regression equation: $\hat{Y} = 18.602 + 0.7592X$. The positive regression coefficient (b) suggests that an increase in X corresponds with an increase in Y, indicating that learning outcomes are directly proportional to mathematical critical thinking abilities. According to Parnawi (2020), learning outcomes reflect the achievements gained through learning activities. These outcomes are influenced by various factors, both internal and external. One significant internal factor is critical thinking ability. Based on Facione's theory, critical thinking encompasses skills such as interpretation, analysis, evaluation, inference, explanation, and self-regulation. These competencies enable students to better understand mathematical concepts, assess problem-solving strategies, and enhance their comprehension of the subject matter (Facione & Facione, 2013).

This is in accordance with the results of the analysis showing that the regression of Y on X is significant, which means that mathematical critical thinking skills influence learning outcomes. Testing the significance of the regression of X on Y, obtained a value of $F_{count} = 77{,}08$, which is greater than $F_{table} = 4{,}04$ at a real level of $a = 0{,}05$ or 5% with degrees of freedom of numerator $df_1 = 1$ and degrees of freedom of the denominator $df_2 = 48$. In addition, the correlation coefficient value of mathematical critical thinking skills (X) on learning outcomes (Y) or $r_{xy}$ of 0,7850, indicating a significant relationship between the two with the value of $t_{count} = 8{,}7794$ which is greater than $t_{table} = 2{,}0106$ at a real level of $a = 0{,}05$ of 5% with degrees of freedom $df = 48$. Based on Table 3.7, the interpretation of the $r_{xy}$, the relationship between these two variables was classified as strong. The magnitude of X's contribution to Y was shown by the coefficient of determination $r_{xy}^2$ of 0,6162 indicating that 61,62% of the variation in students' learning outcomes (Y) can be explained by mathematical critical thinking skills (X). The remaining 38,38% was influenced by other factors not examined in this study. This significant relationship is supported by the results of studies conducted by Fachriani (2020), Saputri et al. (2020), and Sari (2022), pointing out that mathematical critical thinking skills have a positive and significant influence on students' learning outcomes(Fachriani, 2020; Saputri et al., 2020; Sari, 2022).

The findings conclude that mathematical critical thinking skills significantly influence student learning outcomes. Students with higher levels of critical thinking skills tend to show better learning outcomes. However, other factors amounting to 38.38% also influence learning outcomes. This means that mathematical critical thinking skills are not the only factor influencing student learning outcomes. Various other factors also play a role, including internal factors such as physical conditions (e.g., health that affects concentration), mental conditions (motivation, self-confidence, and stress management), and psychological conditions (learning styles, emotions, or interest in the subject). Additionally, external factors have a significant contribution, such as family environment (parental support, family economic conditions, or study atmosphere at home), school environment (learning facilities, classroom atmosphere, or educational policies), and teaching methods and strategies applied by teachers. For example, interactive and contextual teaching approaches can increase students' interest and learning outcomes.

Considering these various factors, the study's findings are expected to provide insights that improving students' learning outcomes does not solely depend on mathematical critical thinking skills but also requires a collective effort to create a supportive learning environment, both from the internal aspect of the student and the external aspects of school and family.

Furthermore, this significant relationship indicates that critical thinking skills are an essential aspect of learning success, with relevance that can be expanded further. In today's world, we live in a sea of information from various sources such as the internet, television, newspapers, school friends, teachers, and others. These streams of information surround us, and we are often confused about determining which information is true and which is false, which is trustworthy and which is not. Frequently, we accept the information presented to us without critically assessing its validity. This is where the need for critical thinking skills becomes essential.

## 4. CONCLUSION

The findings of this study reveal that the mathematical critical thinking skills of Grade XI students at SMA Negeri 7 Gorontalo in the matrix topic are relatively low, with an average achievement score of 56.48%, while their learning outcomes in the TP matrix average 59.66%. Results from the simple linear regression and correlation analyses indicate a positive and significant relationship between students' mathematical critical thinking skills and their learning outcomes. Specifically, critical thinking skills contribute 61.62% to the variance in learning outcomes, suggesting that students with stronger critical thinking abilities tend to perform better academically. However, this study is limited in scope, focusing only on a single school, subject area, and academic level, which may restrict the generalizability of the results. Future research should consider involving a broader and more diverse sample, integrating multiple topics or grade levels, and examining additional internal or external factors that may influence learning outcomes. Additionally, longitudinal or experimental designs could provide deeper insight into how targeted interventions to improve critical thinking skills affect academic performance over time.

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