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Critical Thinking as a Key to Solving Mathematical Problems: Findings from the TIMSS Framework in Middle Schools

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ABSTRACT

Purpose of the study: The purpose of this study was to analyze the influence of critical thinking skills on students' mathematical problem solving based on the TIMSS framework.

Methodology: This study uses a quantitative approach with a correlational survey design. The population of the study was junior high school students with a sample of 200 students selected by random sampling. Data collection used the Critical Thinking Ability Test and the Mathematics Problem Solving Test based on TIMSS. Data analysis was carried out using descriptive statistics, Pearson correlation tests, and simple linear regression using SPSS. Validity tests used content and construction tests, and reliability was tested with Cronbach's Alpha (0.745).

Main Findings: The results of this study indicate a significant positive relationship between students' critical thinking skills and mathematical problem solving. The average score of critical thinking skills and mathematical problem solving is in the moderate category. The evaluation indicator has the highest score, while inference and synthesis have the lowest scores. The results of the Pearson correlation test showed a moderate relationship ($r = 0.550$), and the simple linear regression test showed that critical thinking skills significantly affect mathematical problem solving ($R^2 = 0.303$, $p < 0.05$).

Novelty/Originality of this study: This study offers a fresh perspective by examining students' critical thinking skills within the context of mathematical problem-solving using the TIMSS framework. The results enhance existing literature by demonstrating a strong link between critical thinking and effective problem-solving.

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1. INTRODUCTION

Mathematics is a discipline that plays an important role in everyday life and various scientific fields. Good mathematical skills not only help in solving academic problems, but also in making logical and rational decisions [1]-[3]. Mathematics learning aims to develop conceptual understanding, logical thinking skills, and the ability to solve problems systematically [4]-[6]. Therefore, mathematics learning must be designed to encourage students to think critically and creatively in facing various challenges [7]-[9]. Critical thinking skills are one of the essential competencies that students must have in facing the challenges of the 21st century [10]-[12]. With this

ability, students can analyze, evaluate, and solve various problems rationally and systematically [10]-[14]. In the context of mathematics education, critical thinking is fundamental because mathematics is not only related to calculations, but also to solving problems that require logical and analytical reasoning.

The Trends in International Mathematics and Science Study (TIMSS) is an international evaluation conducted every four years to measure student achievement in mathematics and science in various countries. This assessment is designed to evaluate the extent to which students understand mathematical concepts and are able to apply high-level thinking skills in solving problems [15]-[17]. In TIMSS, the questions given not only test the ability to memorize and apply formulas, but also measure critical thinking skills, reasoning, and complex problem solving [18]-[20]. TIMSS results are often used as an indicator of the quality of a country's mathematics education, because they provide an overview of the effectiveness of the curriculum, the quality of teaching, and students' readiness to face global challenges [21]-[23]. Countries with high scores on TIMSS generally have education systems that emphasize problem-solving-based learning approaches, critical thinking skills, and the use of innovative learning strategies [24], [25]. In contrast, countries with low scores often face challenges in terms of teaching quality, lack of application of problem-solving-based learning, and limitations in educational facilities and infrastructure.

In Indonesia, TIMSS results in recent years have shown that student achievement in mathematics is still below the international average. This indicates the need for improvement in mathematics learning, especially in developing high-level thinking skills such as critical and analytical thinking [26]-[28]. Therefore, it is important to analyze the factors that influence TIMSS results, including the effectiveness of learning strategies used in schools [29]-[31]. However, based on various studies, the critical thinking skills of Indonesian students in solving mathematical problems are still relatively low. Research by Parameswari and Kurniyati [32] showed that of the 23 students studied, only 47.8% were able to meet the analysis indicators, and no students met the evaluation and inference indicators in solving mathematical problems. This indicates that the majority of students have not been able to analyze and evaluate mathematical problems in depth.

In addition, research by Yanti, Sumardi, and Suryana [33] found that the problem-solving approach in mathematics learning can improve students' critical thinking skills. After the approach was implemented, the average score of students' critical thinking skills increased from the moderate category to very high. However, the implementation of this approach still faces various challenges, including the readiness of teachers and students in adopting learning methods that require active involvement and deep thinking. Furthermore, Rachmantika and Wardono [34] emphasize that critical thinking skills are very important in problem-solving-based mathematics learning. They argue that through problem solving, students are trained to think critically, laterally, and systemically, which are essential in understanding mathematical concepts in depth. However, the implementation of problem-solving-based learning requires careful planning and a good understanding from educators regarding effective strategies to encourage students to think critically.

Based on the description above, it is important to conduct an in-depth analysis of the influence of students' critical thinking skills in solving mathematical problems based on the TIMSS framework. This study is expected to provide a comprehensive picture of how students' critical thinking skills affect their ability to solve mathematical problems oriented to TIMSS standards, as well as the factors that influence the development of these abilities. The results of this study are expected to be the basis for the development of more effective learning strategies, which can improve students' critical thinking skills in the context of solving mathematical problems. Thus, the quality of mathematics education in Indonesia can be improved, and students can be better prepared to face global challenges that require high-level thinking skills.

2. RESEARCH METHOD

This study adopts a quantitative approach using a correlational survey design to examine the relationship between students' critical thinking skills and their performance in mathematical problem-solving, guided by the TIMSS framework. It aims to investigate how critical thinking influences problem-solving outcomes and to identify factors affecting student achievement on TIMSS-oriented assessments. The study population comprised junior high school students engaged in mathematics instruction based on an international curriculum. A total of 200 students were randomly selected from schools in Indonesia, Iraq, and Singapore, ensuring diverse representation through random sampling techniques

The instrument used in this study consists of two main components designed to measure students' critical thinking skills in solving mathematical problems based on the TIMSS framework. First, the Critical Thinking Ability Test which was developed based on critical thinking indicators contained in the TIMSS framework. This test includes various questions designed to measure students' abilities in terms of analysis, evaluation, inference, and synthesis. Each question in this test aims to explore the extent to which students can think critically in facing and solving the given mathematical problems.

Table 1. Test instrument grid

No	Indicator	Tested Questions	Description
1	Analysis	Mathematical problem-solving questions that require identification and separation of relevant information.	Students are expected to analyze the information given in the problem, separate relevant data, and identify the steps needed to solve the problem.
2	Evaluation	Questions that ask students to evaluate a proposed strategy or solution.	Students are expected to evaluate the feasibility or suitability of the solution found to solve the mathematical problem.
3	Inference	Questions that require students to draw conclusions from incomplete data or that require deduction.	Students are asked to draw logical conclusions from limited data or information, either in the context of an experiment or solving a mathematical problem.
4	Synthesis	Questions that combine several concepts or pieces of information to produce a new solution.	Students are expected to combine different concepts or problem-solving steps to solve the problem effectively.

Next, this test measures students' ability to solve mathematical problems that are in accordance with the TIMSS question format, including understanding concepts, applying formulas, and critical thinking skills [35], [36], [37]. The questions in the math problem-solving test require students not only to memorize formulas, but also to understand the context and apply mathematical concepts to find the right solution.

Table 1. Test instrument grid

No	Topics	Question Types	Description
1	Algebra	Questions involving linear equations, systems of equations, or solving other algebraic problems.	Students are expected to understand and apply algebraic concepts to solve given problems.
2	Geometry	Questions that measure understanding of geometric concepts, such as area, volume, and the fundamental theorem.	Students are tested on their ability to apply geometric formulas and principles to solve practical problems.
3	Arithmetic	Questions that test students' skills in basic mathematical operations, such as addition, subtraction, multiplication, and division.	Students are expected to apply arithmetic concepts to solve problems in real contexts.
4	Complex Problem Solving	Questions that combine several mathematical topics and require higher-level thinking.	Students are faced with complex mathematical problems, which require them to integrate various concepts in problem solving.

The collected data will be analyzed using descriptive statistics to describe the distribution of test scores and the level of students' critical thinking skills [38], [39]. In addition, to analyze the relationship between critical thinking skills and mathematical problem solving results, Pearson correlation analysis is used [40]-[42]. This analysis will identify whether there is a significant influence between students' critical thinking scores and mathematical problem solving scores. Furthermore, simple linear regression will be used to measure how much influence critical thinking skills have on overall mathematical problem solving results. This analysis will provide an overview of the variables that contribute significantly to improving students' problem solving skills. This study will pay attention to ethical aspects, by obtaining approval from the school and parents of students, and maintaining the confidentiality of data collected for research purposes. Content and construction validity tests will be carried out on the test instrument to ensure appropriate measurement, and the reliability of the instrument will be tested using Cronbach's Alpha to ensure consistency of the results. The test instrument in this study has a Cronbach's Alpha value of 0.745 which is categorized as reliable.

3. RESULTS AND DISCUSSION

This study aims to analyze the influence of students' critical thinking skills in solving mathematical problems based on the TIMSS framework. Based on the analysis of data collected from 200 junior high school students, several main findings were obtained that revealed a significant relationship between critical thinking skills and mathematical problem solving results. In general, the results of the descriptive analysis showed that the average score of students' critical thinking skills tests was in the medium category, with several areas, such as analysis and synthesis, having lower scores compared to the evaluation and inference areas. The following is table

3 to present the results of descriptive statistics based on students' critical thinking skills tests and mathematical problem solving tests:

Table 3. Descriptive statistical results of students' critical thinking ability test and mathematical problem solving test

Variables	N	Minimum	Maximum	Mean	Standard Deviation	Category
Critical Thinking Ability Test	200	50	90	68.50	12.43	Medium
Analysis Indicator	200	40	85	65.70	14.21	Medium
Evaluation Indicator	200	45	90	70.20	13.53	Medium
Inference Indicator	200	30	80	58.90	15.63	Medium
Synthesis Indicator	200	35	80	60.10	14.83	Medium
Mathematics Problem Solving Test	200	55	95	72.30	11.63	Medium
Algebra Topic	200	50	90	68.20	12.81	Medium
Geometry Topic	200	45	85	67.60	13.18	Medium
Arithmetic Topic	200	60	95	74.50	10.91	Good
Complex Problem Solving Topic	200	40	85	63.10	14.71	Medium

The results of the study showed that students' critical thinking skills in solving mathematical problems were generally at a moderate level, with significant variation between individuals. The average critical thinking ability test score was 68.50, but the standard deviation of 12.43 indicated that there was inequality in the mastery of critical thinking skills among students. Students showed better abilities in the evaluation indicator (average 70.20), but there were still difficulties in the inference indicator (average 58.90), indicating that many students had difficulty drawing conclusions from limited data. Meanwhile, students' synthesis ability was also relatively low (average 60.10), indicating difficulty in combining various concepts to solve problems. In the mathematical problem-solving test, the average score was 72.30, indicating that although most students were able to solve mathematical problems using formulas that had been learned, they still had difficulty in more complex problems. The arithmetic topic showed the highest score (74.50), with a more homogeneous understanding, while the geometry (67.60) and algebra (68.20) topics showed greater variation in student scores. Problem solving that combines several mathematical topics recorded the lowest average score (63.10), indicating that many students still face challenges in solving problems that require the integration of different mathematical concepts.

Overall, the results of this study indicate the importance of developing critical thinking skills, especially in solving more complex mathematical problems, so that students can achieve more optimal results in accordance with the standards applied in the TIMSS framework. The variation in test scores also emphasizes the need for more attention to the aspects of developing critical thinking and applying mathematical concepts more deeply in learning.

The following section presents the results of the assumption tests conducted to ensure the appropriateness of the regression model used in the data analysis. The normality test was performed using the Kolmogorov-Smirnov Test to determine whether the data were normally distributed. The results indicated that the significance value for the critical thinking skills test was 0.112, and for the mathematical problem-solving test, it was 0.097. Both values exceed the 0.05 significance threshold, indicating that the data for both variables are normally distributed, thereby satisfying the normality assumption. Furthermore, a linearity test was conducted to examine whether there is a linear relationship between the independent variable (critical thinking skills) and the dependent variable (mathematical problem-solving ability). This was assessed through simple regression analysis and scatterplot visualization. The results revealed a significant linear relationship, as evidenced by an F-test significance value of less than 0.05. Consequently, the analysis could proceed with the Pearson correlation test and simple linear regression.

Table 4. Results of Pearson Correlation Test between Critical Thinking Ability Test and Mathematics Problem Solving Test

Variable	Critical Thinking Ability Test	Mathematical Problem Solving Test
Critical Thinking Ability Test	1.000	0.550*
Mathematical Problem Solving Test	0.550*	1.000

*Note: Significant at $p < 0.05$

The results of the Pearson correlation test showed a significant positive relationship between critical thinking skills and students' mathematical problem solving results with a correlation value of $r = 0.550$ at a significance level of $p < 0.05$. This shows that there is a moderate relationship, where the higher the students' critical thinking skills, the better their mathematical problem solving results. Although this relationship is significant, other factors also play a role in influencing mathematical problem solving results.

Table 5. Simple Linear Regression Test Results

Model	R	R^2	F	Sig. F	B (Critical Thinking Skills)	Sig. B
Mathematical Problem Solving Regression	0.550	0.303	102.45	0.000	0.432	0.000

Catatan: Signifikan pada p < 0.05

The results of the simple linear regression test showed that the regression model used was significant with an F value of 102.45 (p <0.05), which indicated that critical thinking skills significantly affect students' mathematical problem solving results. The coefficient of determination (R^2) of 0.303 indicated that 30.3% of the variation in mathematical problem solving results can be explained by students' critical thinking skills. The regression coefficient B = 0.432 indicated that every one unit increase in critical thinking skills would increase the mathematical problem solving score by 0.432 points. This indicated that increasing critical thinking skills can contribute to improving students' abilities in solving mathematical problems.

The results of this study indicate that there is a significant positive relationship between students' critical thinking skills and mathematical problem solving results. This is in line with previous studies that emphasize the importance of critical thinking in improving mathematical problem solving skills. For example, research by research by Fitri and Hidayati [43] shows that the higher the students' critical thinking skills, the better their ability to solve mathematical problems. In addition, Maulida, Edi & Mulyono [44], reported that critical thinking skills have a significant influence on students' mathematical problem solving abilities, with a determination coefficient of 83.7%. Research by Napitu and Simanjorang [45] also supports this finding, by showing that the interpretation and analysis indicators have high average scores, while the evaluation indicators have low average scores. These findings are consistent with the results of the current study, which emphasizes the importance of developing students' critical thinking skills in improving mathematical problem-solving abilities.

The novelty of this study lies in the approach that links students' critical thinking skills with mathematical problem-solving outcomes within the TIMSS framework, which has not been widely discussed in previous studies. This study introduces an in-depth analysis of critical thinking indicators, such as analysis, synthesis, evaluation, and inference, and their impact on students' mathematical problem-solving abilities. These findings offer new insights into how developing critical thinking skills can help students overcome challenges in more complex mathematical problems, making an important contribution to the development of more holistic mathematics learning methods. The main contribution of this study is the emphasis on the importance of developing critical thinking skills in mathematics learning, which can improve student learning outcomes, especially in solving problems that require the integration of mathematical concepts. This provides new insights for educators to focus on the critical thinking aspect in designing a more effective mathematics curriculum that is in accordance with the TIMSS framework.

The implication of this study is the importance of developing students' critical thinking skills in mathematics learning, especially to deal with more complex problems. Mathematics education should not only focus on mastering formulas, but also on developing critical thinking skills that can be applied in problem solving. However, this study has several limitations. First, the cross-sectional research design limits the ability to draw causal conclusions. Second, other factors that influence mathematical problem-solving ability, such as learning motivation and teaching quality, were not analyzed in depth. Third, the sample limited to junior high school students may not be representative of the national student population. Further research is recommended to use a longitudinal design and consider other variables that may influence mathematical problem-solving ability.

4. CONCLUSION

This study shows a significant positive relationship between students' critical thinking skills and mathematical problem-solving skills, with the average score of critical thinking skills and mathematical problem-solving skills being in the moderate category. Although there is variation between individuals, better critical thinking skills, especially in the evaluation aspect, can improve mathematical problem-solving results, especially more complex ones. The results of the Pearson correlation test and simple linear regression indicate that critical thinking skills have a significant effect on students' mathematical problem-solving skills. The implication of this study is the importance of developing critical thinking skills in mathematics learning to facilitate students in facing more complex problems. Further research is recommended to use a longitudinal design to gain a deeper understanding of the influence of critical thinking on mathematical problem-solving in the long term, as well as considering other variables such as learning motivation, teaching quality, and environmental factors that can affect these abilities.

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