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Critical thinking skills of junior high school students in solving geometry problems

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Abstract
This study aims to describe the critical thinking skills of junior high school (SMP) students in solving geometry problems. A descriptive qualitative approach was used, involving six eighth-grade students selected through purposive sampling. The subjects consisted of two students from each category of mathematical ability: high (T_1 & T_2), medium (S_1 & S_2), and low (R_1 & R_2). The six students were selected based on their performance in the written test and their verbal communication skills, as observed during the pre-research phase, to ensure a more accurate representation of the population. Data were collected through written tests consisting of two essay questions and semi-structured interview guidelines developed based on Facione's critical thinking indicators: interpretation, analysis, evaluation, and inference. The research data collected were written test results and interviews, which were then analyzed based on critical thinking indicators. The results showed that interpretation was the indicator most easily achieved by all subjects, analysis was optimally achieved only by students with high mathematical ability, while evaluation and inference were the most difficult indicators to fulfill. The study concludes that students' critical thinking skills in solving geometry problems are generally low, primarily because of insufficient mastery of the underlying material.

Keywords: critical thinking skills; problem-solving; geometry

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I. Introduction

To be able to compete and survive in the era of information flow in this century, individuals need to think critically in facing various challenges (Faradina, As'ari, & Sukoriyanto, 2019; Kurniawan, Hidayah, & Rahman, 2021; Prajono, Gunarti, & Anggo, 2022; Rahayu, Wibowo, & Kurniawan, 2023; Zebua, Zega, & Telaumbanua, 2024). Critical thinking skills are taught in schools to help students address problems in their environment, including connecting science with real-world contexts, as students are required to think critically in mastering technology and information (Hidayanti, As'ari, & Daniel, 2016; Nurhayati, Asrin, & Dewi, 2022; Wati, Maison, & Syaiful, 2024). This opinion is relevant to the statement that critical thinking is essential for inquiry and is

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helpful in education, personal life, and society. Facione (1990, 2015) states that critical thinking skills are important in mathematics learning because they provide many benefits, such as helping students analyze appropriate material to solve mathematical problems and training them to be meticulous when evaluating their own work. Instilling mathematical critical thinking skills in students is very important because it can help them analyze, reason, and solve mathematical problems and make appropriate and reliable decisions in various aspects of life (Haeruman, Rahayu, & Ambarwati, 2017; Hidayat, Akbar, & Bernard, 2019; Sulistiani & Masrukan, 2016; Syarifuddin, & Fauzia , 2021). Therefore, critical thinking is essential in mathematics education.

Critical thinking skills are essential in education as part of a habitual process, and they have become one of the learning objectives, including in mathematics. This is supported by the Indonesian government through the Ministry of Education and Culture Regulations (Permendikbud) No. 20 and No. 21 of 2016, which emphasize the importance of critical thinking in every learning process. Mathematical critical thinking skills play a vital role in mathematics and are classified as higher-order thinking skills that are crucial to develop (Fatmawati, Merdiyana, & Triyanto, 2014; Rosdiana, 2020; Yulia & Ferdianto, 2023). Critical thinking skills are cultivated through educational processes, and in mathematics, students need to become reliable problem solvers, sound decision-makers, and lifelong learners (Astuti, Purwoko, & Indaryanti, 2017). Critical thinking skills can stimulate Students' mathematical abilities, as they are expected to solve mathematical problems involving knowledge, reasoning, and proof (Ennis, 2011; Faradina et al., 2019; Mardiyanti, Afrilianto, & Rohaeti, 2018). (Anggraini, Siagian, & Agustinsa, 2022). Furthermore, Gokhale in Hendriana and Soemarmo (2014) defines critical thinking problems as involving analysis, synthesis, and evaluation of a concept. Based on this explanation, students' mathematical abilities and the urgency of critical thinking skills in today's era demand that educational institutions prepare and train their students to develop critical thinking.

Although critical thinking skills are essential and a goal of mathematics learning, data shows that Indonesian students’ critical thinking abilities remain low. Previous research conducted by Fitriana et al. and Hidayanti et al. demonstrated that students struggle to analyze problems critically, provide logical reasoning, and evaluate their solutions (Fitriana, Marsitin, and Ferdiani 2019; Hidayanti et al., 2016). Consistent with these findings, preliminary research data obtained by the authors also revealed that many students could not identify key information in geometry problems, connect concepts accurately, or justify their answers logically. These shortcomings indicate a significant gap between students' abilities and the learning objectives stated in Permendikbud No. 22 of 2016, especially regarding geometry content requiring higher-order thinking. Despite the recognized importance, prior studies indicate that students’ critical thinking skills, especially in geometry, remain underdeveloped, warranting further investigation. The novelty in this study is describing what indicators are lacking at each level of mathematical ability (high, medium, low) so that it can be a basis for developing students to become critical thinkers.

The importance of geometry makes it a necessary subject to be taught at every educational level and a core standard in mathematics. This is because geometry holds a significant role in daily life. Geometry is an important branch of mathematics that is beneficial in everyday life. It involves visualization and the connection between mathematics and real-world contexts, making it a subject that students must master in order to gain practical benefits in their lives (Novianda & Turmudi, 2021; Suhartini & Martyanti, 2017) Walle, as cited in Sofyan, Sumarni, & Riyadi. (2021), asserts that geometry provides a comprehensive understanding of the world and plays an important role in learning other mathematical concepts. Astuti et al., 2017 state that geometry learning aims to develop problem-solving skills using logical and mathematical reasoning, thereby allowing students to cultivate their intuition as they explore the world of geometry, which they have been introduced to since elementary school. Additionally, geometry supports the understanding of other mathematical concepts. Problem-solving in geometry involves applying previously acquired geometric knowledge to solve new problems or situations (Jupri, Nurlaelah, & Dahlan, 2022). Based on the explanation above, an analysis of junior high school students' critical thinking abilities in solving geometry problems is needed. Therefore, this study aims to describe junior high school students' critical thinking abilities in solving geometry problems, focusing on each Facione critical thinking indicator.

II. Research Method

This study is descriptive qualitative research. Descriptive qualitative research aims to describe several variables related to the problem under investigation (Samsu, 2021). Furthermore, Sukmadinata (2015) states that descriptive research aims to provide descriptive information about a condition or situation without manipulating it in the field. The research procedures carried out by the researchers were as follows: (1) preliminary research, where the researchers' conducted observations and interviews with mathematics teachers at the school; (2) primary research, where the researcher conducted the study by administering a written test consisting of two geometry problems and conducting interviews with the subjects; and (3) data processing.

The interview process was conducted immediately after students completed the written test on the same day to ensure the authenticity and accuracy of students' answers. The interview aimed to clarify students' answers and increase the validity of the data. During the interview, the conversation was recorded and then transcribed for further analysis. In addition, researchers also observed students' behavior during the research process to obtain more comprehensive data.

This research was conducted at one of the public junior high schools (SMP Negeri) located in Malang Regency, involving six 8th-grade students as research subjects. The six students were selected from 22 students using a purposive sampling technique. Students were assigned the task of solving geometry problems. The researcher then collaborated with the mathematics teacher to classify the students into three categories of mathematical ability: high, medium, and low, based on their work. Subsequently, two students from each mathematical ability group were selected based on their potential to represent their respective groups.

The test instrument used in this study consisted of two open-ended geometry questions that an expert or validator had validated. The validity and reliability of the mathematical problems and interview guidelines were tested with the involvement of expert lecturers as validators. The written test was validated to ensure that the questions were understandable to students and free from ambiguity, while the interview guidelines were validated to elicit insights that might not be visible in students' written responses. Thus, the research instruments used were confirmed to collect accurate, valid, and reliable data to achieve the research objectives based on critical thinking indicators.

The critical thinking test developed by the researchers included two similarity-related problems. The first problem was: "*There are two circles of different sizes: a small circle with a radius of 2 cm and a large circle with a radius of r cm. Given that the ratio of the area of the small circle to the large circle is 4:9, do you agree that the ratio of the areas and the ratio of the circumferences of the two circles are the same? Explain your reasoning.*" The second problem was: "*Mr. Joko owns two triangular plots of land, each with an area of 100 m². He plans to pass these plots down to his two sons, Aguk and Dodit,* *each receiving one plot. Are the shapes of Aguk's and Dodit's plots congruent? Explain your reasoning.*" These two questions were administered to the selected subjects with an allotted time of 60 minutes. The students' responses were then analyzed based on critical thinking indicators adopted from(Facione (1990, 2015). The indicators of critical thinking used in this study are described in Table 1 below.

Table 1
Description of critical thinking indicators

Indicator	Description
Interpretation	Understanding the meaning and purpose of a mathematical statement or problem. This is shown by accurately describing the known information and the questions asked.
Analysis	Identifying relationships between information, concepts, and problem-solving strategies. This is demonstrated by relating obtained information to other material concepts.
Evaluation	Assessing the validity and logic of statements or problem solutions. This is indicated by evaluating claims or arguments from the results.
Inference	Drawing logical conclusions based on reasonable justification. This is shown by providing accurate solutions based on what is asked.

The students' critical thinking skills data were collected and organized into a single folder to facilitate analysis. Specific codes were used to identify aspects of critical thinking, such as interpretation (I_1), analysis (A), evaluation (E), and inference (I_2). The test results and interview transcripts were presented narratively to provide a clearer picture of the research findings. In this way, the researcher could draw accurate and precise conclusions.

III. Results and Discussion

Results

As explained in the research method, the subjects in this study consisted of 6 eighth-grade students selected from 22 students. In the preliminary stage, students were given geometry problems to assess their ability to solve them, followed by interviews to evaluate their ability to communicate their answers. The researchers also conducted interviews with the mathematics teachers to help determine students' mathematical abilities, resulting in the selection of two students, each representing high ability (T_1 and T_2), moderate ability (S_1 and S_2), and low ability (R_1 and R_2).

For problem number 1, in the interpretation indicator, most subjects could identify the given information and what was asked in the problem quite well. Subjects T_1 and T_2 demonstrated excellent interpretation skills by listing information from the problem, such as the radii and area ratio, writing down what was asked, and explaining the meaning of symbols and variables. Subjects S_1 and S_2 also showed an understanding of the problem, but their presentation was less systematic, with incomplete or inaccurate information. Subject R_1 failed to understand the problem as they could not write down the necessary basic information. Subject R_2 only wrote part of the information with a shallow understanding, indicating misconceptions. Based on these data, it is known that all students were able to achieve the interpretation indicator in problem number 1.

In the analysis indicator, students reflected on their ability to connect the known information with mathematical concepts. Subjects T_1 and T_2 could construct mathematical models to solve the problem well. T_1 even simplified the area ratio formula into root form and related it to the circumference of the circles. Subjects S_1 and S_2 showed partial ability, understanding that the area formula must be used but struggling to construct a mathematical model or use symbols and units consistently. Subjects R_1 and R_2 did not show adequate analytical ability; their answers did not reflect an understanding of the relationship between the area and circumference of the circles. There are 5 out of 6 students who can achieve the analysis indicator.

The evaluation indicator, which assesses students' ability to review the validity and logic of their process or results, rarely appeared in students' written answers and was mainly evident from interviews. Subject T_1 was evaluated by comparing the ratio of circumferences with the ratio of areas and realized that the results differed. Subject T_2 did not perform a complete evaluation; the process was correct, but the final calculations were not rechecked, leading to unnoticed numerical errors. Students S_1 and S_2 did not evaluate adequately; neither reviewed their process or results nor recognized potential logical errors. Students R_1 and R_2 did not perform any evaluation in writing or orally. Based on the explanation above, only 2 out of 6 students can achieve the evaluation indicator.

In the inference indicator, all subjects provided conclusions, but not all drew logical ones. Participants T_1 and T_2 were able to make logical conclusions. T_1 stated that the ratios of area and circumference were not the same, while T_2 concluded a relationship between the two despite having some calculation inaccuracies. Participants S_1 and S_2 could not draw clear or logical conclusions from their answers; their statements were not based on strong analysis or evaluation. Participants R_1 and R_2 could not conclude or complete the problem-solving process until the inference stage. There are only 2 out of 6 students who can make inferences. Figure 1 is one of the student's works for problem number 1, which can achieve all indicators but is still not careful when evaluating.

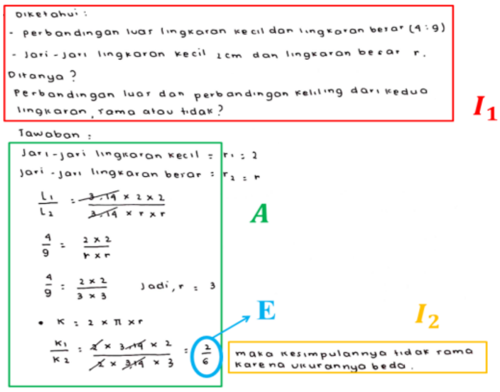

Figure 1. One of the student's works for problem number 1

For problem number 2, in the interpretation indicator, subjects T_1 and T_2 demonstrated good understanding; both identified two triangular plots of land given to two children and recognized that comparing the shapes is related to the concept of congruence. Subjects S_1 and S_2 somewhat understood the story's context but had difficulty identifying key terms or concepts, such as the meaning of congruence. The information written by subjects S_1 and S_2 was incomplete or inaccurate. Subjects R_1 and R_2 failed to comprehend the problem's content, did not show recognition of the relevant geometric shapes, and their explanations did not correctly address the issue of congruence. Based on these data, it is known that only 4 out of 6 students were able to achieve the interpretation indicator.

At the analysis stage, the focus was on the student's ability to connect the information from the problem with the conditions under which two triangles can be said to be congruent. Participant T_1 attempted to depict several possible triangle shapes as plot possibilities but did not correctly apply the congruence criteria, indicating that the analysis was still inaccurate. Participant T_2 identified three out of four congruence criteria for triangles (SSS, SAS, ASA), though not wholly; the subject tried to compare the sides and angles that the two plots might have. Participants S_1 and S_2 appeared to rely on intuitive reasoning when identifying the triangle shapes without explicitly connecting the information provided to the formal principles of triangle congruence. Participants R_1 and R_2 could not connect any information to the concept of congruence, resulting in minimal or irrelevant analytical efforts. There are 2 out of 6 students who were able to achieve the analysis indicator.

Subject T_1 was not evaluated in the evaluation stage because more time was spent guessing possible shapes rather than verifying logically. Subject T_2 showed an effort to evaluate by stating that the information given was insufficient to conclude whether the two plots were congruent and realized that there was no data about side lengths or angle measures provided.

Subjects S_1 and S_2 did not critically evaluate the information and only stated "maybe the same" or "could be different" without in-depth arguments. Subjects R_1 and R_2 did not conduct any evaluation during their problem-solving steps. Their answers were unstructured and showed no signs of reflection. Based on the explanation above, only 1 out of 6 students achieved the evaluation indicator.

In the inference stage, similar to the responses for problem number 1, not all students provided logical answers to conclude. Student T_1 only gave speculative answers without a strong logical basis, so it cannot be said that proper inference was made. Student T_2 concluded that the two triangles were incongruent because the information was insufficient (e.g., side lengths and angles were unknown). Students S_1 and S_2 did not draw valid conclusions because they only guessed without linking their conclusions to the available data. Students R_1 and R_2 did not draw any relevant conclusions or final statements about the problem. Their problem-solving process was interrupted before reaching the inference stage. Only 1 out of 6 students was able to make an inference. Figure 2 is one of the student's works for problem number 2, which achieved the interpretation indicator but did not achieve the other indicators.

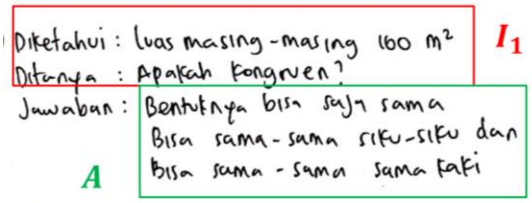

Figure 2. One of the student's works for problem number 2

Discussion

The critical thinking ability in this study was still categorized as low. This finding is consistent with previous research by Fitriana et al. (2019) and Hidayanti et al. (2016), which reported that junior high school students' critical thinking skills remain underdeveloped or low. According to Fatimah, Gunawan, & Wahyudi (2017), this low level of critical thinking results from students' inadequate understanding of mathematical concepts. The lack of critical thinking skills also leads to serious issues such as low self-confidence, difficulty making decisions, challenges in problem-solving, and a negative impact on students' self-concept in responding to their environment (Kurniawan et al., 2021).

All participants met the interpretation indicator. Students could write down and explain the information from the problem, although with varying degrees of completeness and accuracy. Facione (1990) defined interpretation as assigning meaning to experiences, statements, and written information. This aligns with Ennis (2011), who stated that providing elementary clarification is the most basic stage of critical thinking. Without identifying the correct information, it is difficult to reach success in the other indicators.

Furthermore, based on the results from problems 1 and 2, it was found that some students were unable to perform analysis, especially in problem number 2. These students responded by guessing, such as by comparing the two land plots as triangles with different shapes instead of using the concept of congruence. During interviews, students admitted that they had either forgotten or did not understand the congruence material, failing to reach the analysis stage. This suggests that their analysis was mechanical rather than reflective, as criticized by Gokhale in Hendriana & Soemarmo (2014), regarding students' weak synthesis ability due to low conceptual understanding.

Next, regarding the evaluation and inference indicators, only students in the high mathematical ability group could meet these criteria, although some still made calculation errors due to a lack of carefulness. Students in the medium and low ability categories could not achieve these indicators due to low confidence and limited knowledge. This aligns with Suhartini & Martyanti (2017), who emphasized that evaluation requires strong self-confidence and a solid understanding. Taube in Hendriana & Soemarmo (2014) noted that students cannot often evaluate arguments internally. Evaluation is the most challenging stage of critical thinking for students, mainly if they are not accustomed to reflecting on their thought processes (Hidayanti et al., 2016). As a result of their inability to evaluate, students also failed to reach the inference stage. This finding supports the view of Peter & Snyder in Hidayanti et al. (2016), who stated that inference heavily depends on the success of the previous thinking processes, or in other words, inference ability will only emerge if the stages of interpretation, analysis, and evaluation are performed correctly.

Students' inability to achieve one indicator affects their ability to reach the next stage. These results also align with Ennis (2011), who defined critical thinking as a logical and reflective process aimed at deciding what to believe or do. In this case, critical thinkers are not only those who solve problems but also those who reflect, evaluate, and draw conclusions.

IV. Conclusion

The analysis and discussion of the data reveal that eighth-grade junior high school students' critical thinking abilities in geometry problem-solving still need improvement. Students could understand the information provided in the problems, although their levels of understanding varied; therefore, the interpretation indicator was achieved. However, only some students could relate the information in the problem to the concepts they had previously learned, indicating that the analysis indicator was not fully achieved. Furthermore, students could not evaluate properly, as not all of them rechecked their answers or problem-solving steps, and many lacked accuracies. The inference indicator was also not achieved because the previous indicators were not fulfilled.

These findings provide insight for teachers and researchers regarding junior high school students' critical thinking skills. It is expected that teachers and researchers can design and develop instructional practices that foster critical thinking, given the importance of such skills in today's era. Suggestions for future researchers include developing various types of critical thinking problems in geometry that can serve as references for educators in teaching students. Additionally, teachers are encouraged to reinforce students' understanding of mathematical concepts and frequently engage students in critical thinking activities in classroom instruction and through assignments involving critical thinking problems. Teachers should also monitor students' progress in critical thinking to help them develop these skills effectively.

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