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Mathematical Critical Thinking Ability of Grade IX Students in Solving Ill-Structured Problems

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Abstract

Students' mathematical critical thinking ability (MCTA) in Indonesia is still low, and one contributing factor is that students are not accustomed to solving non-routine problems, including ill-structured problems. This research aimed to explore the mathematical critical thinking ability (MTCA) in solving ill-structured using a qualitative approach with a case study method. This research involved 24 grade IX students from a junior high school in Bandung City, Jawa Barat Province, who had learned quadratic equations. Data were collected through a written test on MCTA and follow-up interviews. The results reveal that students fail to meet the MCTA indicators due to their lack of practice in solving contextual problems on quadratic equations and ill-structured problems. In addition, to gain a deeper understanding of mathematical critical thinking ability and the ability to solve ill-structured problems, future researchers could use two separate instruments, as these abilities involve distinct cognitive processes: convergent thinking and divergent thinking.

Keywords: Junior high school, Mathematical critical thinking ability, Ill-structured problems

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INTRODUCTION

Mathematics has a crucial role in everyday life, and it is characterised by its support of various sectors of human life, including the development of science and technology. Therefore, mathematics is one of the subjects that must be studied at school. Mathematics is a science formed through human thought processes related to ideas, processes, and reasoning (Simangunsong et al., 2021). Mathematics is also often referred to as a way of thinking, so learning mathematics can help students improve their thinking skills.

According to Coffman (2013), there are two thinking skills: lower-order thinking skills (LOTS) and higher-order thinking skills (HOTS). LOTS requires students to answer factual questions with a single answer, which can be found directly in books or through memorisation. Meanwhile, HOTS requires students to understand, interpret, analyse, and interpret information (Syaodih et al., 2022). In addition, according to Imran and Partikasari (2020), thinking ability consists of four levels: recall thinking, basic thinking, critical thinking, and creative thinking. Based on this, the ability to think critically is one of the abilities students must possess.

Critical thinking ability prepares students to think in various disciplines. According to Ennis (1991), critical thinking is a person's ability to analyse, evaluate, and conclude information or arguments objectively and rationally. Critical thinking is actively, consistently, and carefully considering a belief or knowledge, which involves evaluating the underlying reasons and anticipating further conclusions (Aiyub et al., 2021). Mathematical elements' distinctive and intricate nature necessitates that students engage in critical thinking during their learning process. Consequently, it is essential to foster critical thinking ability to address problems and derive conclusions from multiple possibilities (Agustina, 2019). A survey by the Association of American Colleges and Universities (AACU) found that 93% of respondents considered critical thinking and problem-solving essential, with over 75% wanting greater emphasis on this ability (Su et al., 2016). However, facts in the field show that mathematical critical thinking ability (MCTA) still tends to be low.

The low level of MCTA is evidenced by the research conducted by Aston (2023), which states that students in the UK often experience difficulties in critical thinking because various factors often hinder them. This condition also happened in Indonesia. According to Agus and Purnama (2022), 94.4% of students had low critical thinking ability. Several other studies show that students' MCTA has not been optimally developed (Rahayu & Dewi, 2022; Budiwiguna et al., 2022). The results of various surveys also reinforce this. The results of the PISA survey 2022, which measured students' abilities based on the level of problems from simple to problems requiring higher-level thinking skills, Indonesia was ranked 70 out of 81 other participating countries with an average score of 366 (OECD, 2023). This condition indirectly shows that Indonesian students' MCTA is still lacking and needs improvement. In addition, the results of the Trends in International Mathematics and Science Study (TIMSS) survey in 2015, which assessed students' critical thinking ability through questions with high cognitive levels, showed that students' critical thinking ability in Indonesia was still low, ranking 44 out of 49 countries with an average score of 397. Students' MCTA in Indonesia is still low because mathematics learning in schools has not fully honed these abilities, and attention to their development is still lacking, so there is an opportunity to explore and develop them further.

Students' MCTA can be developed through learning at school. The results of research from Utami et al. (2022) state that improving critical thinking ability is prioritised in learning mathematics at school so that students can get used to solving non-routine problems requiring more profound and complex thinking. However, this is not in line with what happened. Widiastuti and Rahmah (2023) stated that students have difficulty solving problems that require critical thinking because students are rarely trained to solve non-routine problems. Thus, students must be accustomed to dealing with various mathematical problems through learning at school.

Mathematical problems are situations or problems that involve mathematical principles. According to Thamsir et al. (2019), mathematical problems are problems whose solutions cannot be found immediately because the solutions do not use routine procedures. Yee (2002) divides problems into closed or well-structured and open-ended or ill-structured problems. Well-structured problems are problems that are clearly formulated and always have one correct answer. In contrast, ill-structured problems are problems that do not have a clear formulation, and no fixed procedure guarantees the correct solution. In addition, Davidson and Sternberg (2003) classify problems based on the clarity of the solution set; well-defined problems have clear goals, solution steps, and solution obstacles based on existing information. Meanwhile, ill-defined problems have a series of unclear solutions, so they require a systematic approach to finding a solution.

Currently, learning in schools only accustoms students to solving well-structured problems. This situation is supported by the results of research from Anggraeni (2021), which states that in the learning practices that have occurred so far, learning mathematics is accustomed to using well-structured mathematical problems without giving ill-structured mathematical problems. This habit causes students to experience difficulties when faced with ill-structured mathematical problems. Meanwhile, according to the results of research from Udyani et al. (2018), students' MCTA is taught with the help of ill-structured problems rather than well-structured problems. Thus, familiarising students with solving ill-structured mathematical problems is expected to improve their critical thinking ability.

Based on the facts that have been presented, the researcher aims to explore students' MCTA when solving ill-structured problems. Therefore, this study is entitled "Students' Mathematical Critical Thinking Ability of Grade IX Students in Solving Ill-Structured Problems."

METHODS

This research explored the mathematical critical thinking ability (MTCA) in solving ill-structured problems among ninth-grade students. Researchers employed a qualitative approach using a case study method to achieve this. This research was conducted at a junior high school in Bandung City, Jawa Barat Province, involving 24 students who had learned quadratic equations. Researchers selected three non-random students based on collected data to represent different MCTA levels.

Data collection utilised both test and non-test techniques. The test involved a written test of students' MCTA. The non-test technique was interview guidelines. Several appropriate instruments were required to facilitate these data collection methods. The research employed two types of instruments: the researcher, as the primary instrument, who was directly engaged in data collection, and various supporting instruments. The written test of MCTA consists of six items representing an indicator of MCTA. The indicator of MCTA, according to Ennis (1991), can be seen in Table 1.

Table 1. The Indicators of Mathematical Critical Thinking Ability (MCTA)

Question Number	The Indicator of Mathematical Critical Thinking Ability (MCTA)
1	Focus (F): Identify the focus or central concern.
2	Reason (R): Identify and judge the acceptability of the reasons.
3	Inference (I): Judge the quality of the inference, assuming the reasons to be acceptable.
4	Situation (S): Pay close attention to the situation.
5	Clarity (C): Check to be sure that the language is clear.
6	Overview (O): Step back and look at it all as a whole.

The written MCTA test given to students has been validated by experts, including mathematics education lecturers and mathematics teachers teaching the subject. A readability test was carried out with students of different math abilities to ensure the test was suitable for all students. In qualitative research, there are four principles, two of which are credibility and transferability. These principles help evaluate the validity and reliability of this test instrument. Three selected students representing MCTA levels were the interview subjects. The interview employed a semi-structured method, with guided questions that were flexibly adjusted based on the subject's responses, allowing for an in-depth exploration of their MCTA.

After collecting the data, the researcher analysed it by first reducing it. The criteria for selecting subjects at each level were students who had relatively similar ways of working on problems with the most ways of working on problems and suggestions from a mathematics teacher. The last data reduction was carried out on the interview transcript. If there was a mismatch between the MCTA test answers and the interview results, then the data were not used in data analysis. The data presented describe the MCTA of students with high, moderate and low levels. The final stage of data analysis was to draw conclusions, which took the form of detailed descriptions.

RESULTS & DISCUSSION

Results

All students' mathematical critical thinking ability (MCTA) test results were categorised at high, moderate, and low levels. The percentage of the categorisation can be seen in Table 2.

Table 2. Percentage Level of Mathematical Critical Thinking Ability of All Students

No	Level Category	Percentage
1	High	8,3%
2	Moderate	79,2%
3	Low	12,5%

Next, three students were selected to represent each MCTA level: S1 for high, S2 for moderate, and S3 for low. The results of the MCTA can be seen in Table 3.

Table 3. Achievement of Subjects with High, Moderate, and Low Levels of MCTA

Subject	1st Indicator	2nd Indicator	3rd Indicator	4th Indicator	5th Indicator	6th Indicator
S1	✓	✓	-	-	-	✓
S2	✓	-	-	-	-	✓
S3	-	-	-	-	-	-

Table 3 shows the outcomes of students' MCTA tests and interviews conducted for this research. High-level MCTA subjects (S1) met three of the six indicators, moderate-level subjects (S2) met two, while low-level subjects (S3) did not meet all the indicators. The figures provided have been translated into English for easier comprehension and to ensure accessibility for a broader reader. The question and an example answer of the first indicators of MCTA can be seen in Figure 1 and Figure 2.

Margasana village has a field that resembles a rectangle. It is known that the length of the field is three times its width. The villagers plan to paint the entire surface of the field. On the outer edges of three sides of the field, a 1 m wide street is made, with a total area of 52 m^2. Margasana Village has 150 kg of paint in stock, and each kilogram of paint can be used to paint 1 m^2 of surface. The following illustrates the shape of the field in Margasana Village.

Is the paint supply enough to paint the entire surface of the field?

a. If yes, state your reasons!
b. If not, explain why and illustrate a painting pattern on the field so that the area painted is exactly 150 m^2!

Figure 1. The Question of the 1st Indicators of MCTA

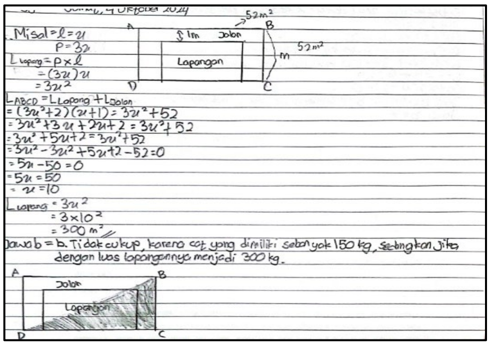

Figure 2. The Answer to Subject S1 on the 1st Indicators of MCTA

Based on Figure 2, subject S2 fulfilled the first indicators of MCTA. Subject S2 understood the problem by mentioning what was known and asked about the problem. In addition, subject S2 made the right decision and argued that the available paint could not paint the entire field. In contrast to the other two subjects, subject S2 illustrated the painting pattern correctly by explaining through an interview that he would paint half of the field area as illustrated on the answer sheet. This result means that subject S2 can solve ill-structured problems in the first indicators of MCTA.

Next, the question and an example answer of the second indicator of MCTA can be seen in Figure 3 and Figure 4.

Take a look at the problem and solution steps below.

PROBLEM

A factory makes two types of cardboard boxes that resemble cubes: cardboard box A and cardboard box B. The volume of cardboard A is $a\ m^3$ and the volume of cardboard B is $b\ m^3$. The factory wants to pack several boxes of both types in a new box with a volume of $100\ m^3$. You know that the volume of cardboard box A is $37\ m^3$ more than twice the volume of cardboard box B. What is the volume of boxes A and B respectively?

COMPLETION STEPS

For example:
x: number of cardboard types A
y: number of cardboard types B
Step 1.
The total volume equation:

$$xa + yb = 100$$

Step 2.
Equation the volume of cardboard box A is $37\ m^3$ more than twice the volume of cardboard box B.:

$$a = b^2 + 37$$

completion steps are still continuing…
Is there a wrong solution step?
a. If yes, at the start of which step was wrong and what should they be?
b. If not, give your reason!

Figure 3. The Question of the 2nd Indicators of MCTA

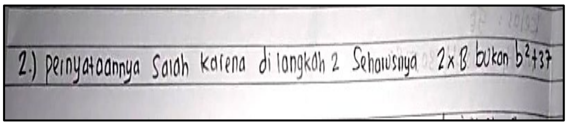

Figure 4. The Answer to Subject S1 on the 2nd Indicators of MCTA

Based on Figure 4, subject S1 fulfilled the second indicator of MCTA, namely correctly determining the wrong solution steps accompanied by appropriate reasons, even though it was not written in detail on the answer sheet. However, subject S1 could not solve the problem until the volume of type A and B cardboard was determined because it was confused about contextual problems. This result means subject S1 could not solve ill-structured problems on the second indicator of MCTA.

Next, on the third indicator of MCTA, subject S1 had difficulty determining the roots of the quadratic equation obtained. This occurred because subject S1 felt anxious about handling larger numbers, as they were only accustomed to working with smaller numbers, from units to tens, in school. The incomplete answer makes students unable to provide a conclusion about the value of $that$ under the context of the problem. Likewise, subject S3 could not understand the problem. Meanwhile, another subject did not understand the problem when the subject first read the problem and ran out of time when the subject wanted to try again to solve the problem. These results mean that all the subjects could not solve the ill-structured problems on the third indicator of MCTA.

Figures 5 and 6 show the question and an example answer for the fourth indicator of MCTA.

A farmer has a rectangular piece of land with an area of 600 m^2. He plans to build a fence around the land. However, due to limited funds, the length of the fence he can build is limited to 120 m. The farmer wants to maximize the area of land that can be fenced with the available fence length. The farmer plans to increase the length and decrease the width of the land by a large size, so that the total perimeter remains 120 m and the area remains 600 m^2. Is the farmer's plan possible?

a. If yes, find at least two different ways in which the farmer's plan can be carried out!
b. If not, give your reasons!

Figure 5. The Question of the 4th Indicators of MCTA

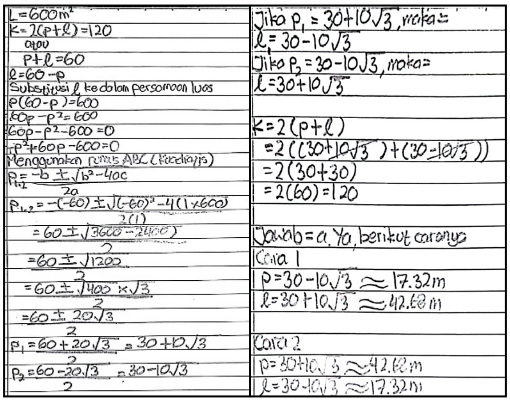

Figure 6. The Answer to Subject S2 on the 4th Indicators of MCTA

Based on Figure 6, subject S2 could not fulfil the fourth indicator of MCTA. Subject S2 could not determine the key to the real problem because the subject did not understand the problem related to the farmer's plan to increase the length and reduce the width of the land. Subject S2 argued that the plan was carried out in the final step by mentioning methods one and two of the answer sheet. This result means that subject S2 could not solve the ill-structured problems in the fourth indicator of MCTA.

On the fifth indicator of MCTA, all subjects could not find the information needed for the right solution. This situation indicates that all the subjects could not solve ill-structured problems on the fifth indicator of MCTA, and the student does not yet possess adequate critical thinking ability. For example, subject S1 could explain the answer, but the explanation was incorrect.

Figures 7 and 8 show the last question and an example answer for the sixth indicator of MCTA.

Johan and Mario worked together to paint the entire wall in 18 minutes. If Johan works alone, it will take him longer than Mario's time. How much time did Johan and Mario each take to paint the wall?
Is the information given in the problem enough to answer the question?

a. If yes, list all the information and calculate the time taken by Johan and Mario respectively!
b. If no, what information is needed and complete the information to calculate the time Johan and Mario each took!

Figure 7. The Question of the 6th Indicators of MCTA

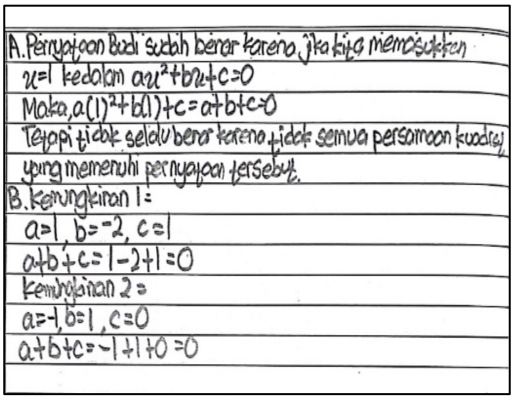

Figure 8. The Answer to Subject S2 on the 6th Indicators of MCTA

Based on Figure 8, subject S2 fulfilled the sixth indicator of MCTA, namely conducting a thorough re-examination to determine the decisions' accuracy. This result indicates that subjects have good critical thinking ability, as critical thinking requires effort to examine beliefs and knowledge based on existing evidence and their conclusions. Subject S2 also provided additional argumentation: not all quadratic equations have the root of the quadratic equation $x = 1$. In addition, subject S2 was also able to answer questions utterly related to the possible values of $a, b,$ and c that fulfilled. This situation means subject S2 was able to solve ill-structured problems in the sixth indicator of MCTA.

Discussion

On the first indicators of MCTA, students who understand the problem by mentioning what was known and asking about the problem can be said to be students who have good critical thinking ability characterised by students who were able to analyse problems that arose and determine attitudes and views on problems that have been studied in learning (Susanto et al., 2023). In addition, students who make the right decision were the students can understand the content of the problem (Winarti et al., 2018). Students who can solve ill-structured problems on the first indicators of MCTA are students who have good critical thinking abilities characterised by analysing and generalising ideas based on existing facts (Rachmantika & Wardono, 2019).

On the second indicator of MCTA, students who correctly determine the wrong solution steps accompanied by appropriate reasons, although the students do not write it down in detail, can help students to express their arguments so that students can develop their mathematical critical thinking ability (Harlita & Ramli, 2018). This also aligns with Widodo et al. (2019), which state that although the subject did not write down what was known and answered, the students could do the process of solving the problem in the answering stage. Next, on the third indicator of MCTA, no students were able to solve the problem characterised by students unable to draw the correct conclusions from the context, so they cannot decide what to believe and do logically (Roviati & Widodo, 2019).

On the fourth indicator of MCTA, Students could not determine the key to the real problem and understand the problem because students could not connect the discussed problem with relevant issues in the situation indicator (Susanto et al., 2023). On the fifth indicator of MCTA, no students can solve ill-structured problems because the terms contained in the problem are not explained. In contrast, one of the key aspects of critical thinking in mathematics is the ability to analyse information (Firdaus et al., 2015) and select and process information from appropriate information (Anisa et al., 2021). On the last indicator of MCTA, students can solve ill-structured problems characterised by students' re-examinations to determine the decisions' accuracy.

Their unfamiliarity with contextual problems causes students' failure to complete MCTA ability tests. Meanwhile, mathematical contextual problems can present real situations that students have experienced, with contexts that are appropriate and related to the mathematical concepts being studied (Kurniasih, 2016). This condition leads to difficulties connecting mathematical concepts with real-life situations and solving problems relevant to everyday life. It also limits their MCTA development. Additionally, the interview results revealed that students mentioned their teachers had never assigned ill-structured problems during classroom lessons. As a result, the students felt confused when faced with such problems.

Overall, it appears that most students could not solve each problem fully. They could only complete the sections involving well-structured problems but not the ill-structured ones. Critical thinking involves analysing, evaluating, and reflecting on information or arguments, often requiring convergent thinking. Convergent thinking is an original and reflective thinking process that involves decision-making abilities. Additionally, convergent thinking encourages individuals to find the correct solution to problems characterised by being vertical, focused, systematic, dependent, and applicable (Rosyid & Thoha, 2018). On the other hand, solving ill-structured mathematical problems requires exploring various possibilities, generating new ideas, and finding innovative solutions. Therefore, it can be said that solving ill-structured problems requires creative thinking ability. Creative thinking is closely related to divergent thinking, characterised by generating multiple ideas or solutions for a problem. Meanwhile, students are only accustomed to working on well-structured problems that do not allow for divergent thinking (Kurniasih, 2016). Divergent thinking is the ability to generate various ideas or solutions to a problem by directing thought differently (Guilford, 1959). This process involves creative exploration, allowing individuals to discover unconventional and innovative approaches.

Convergent and divergent thinking are vital for problem-solving, with convergent thinking identifying the best solution and divergent thinking generating multiple ideas. Both are necessary for producing effective and innovative solutions. Therefore, different assessment instruments are required to gain a deeper understanding of students' critical thinking ability and their ability to solve ill-structured problems.

CONCLUSION

Based on the research results of students' MCTA in solving ill-structured problems, it is concluded that students fail to meet the indicators of MCTA due to their lack of practice in solving contextual problems on quadratic equations and ill-structured problems. On the first indicator of MCTA, most students can meet this indicator by focusing on a problem and making decisions, allowing them to solve ill-structured problems. Some students can meet the second indicator of MCTA by arguing about the given solution. However, most students could not fully solve the problem, indicating they could not complete the ill-structured problems. Furthermore, no students could meet indicators 3, 4, and 5. Students' failure to meet the third indicator of MCTA is due to a lack of understanding of the problem, making them unable to determine the steps to solve it and draw the correct conclusion. The failure to meet the fourth indicator of MCTA is due to students not being able to identify the key issue of the problem. Meanwhile, students failed to meet the fifth indicator of MCTA because they could not correctly explain the solution based on the given information. Some students could meet the sixth indicator of MCTA because they could conduct checks and make the right decisions, allowing them to solve ill-structured problems. Future researchers could use separate instruments to understand MCTA and the ability to solve ill-structured problems better, as these abilities involve different cognitive processes: convergent thinking and divergent thinking.

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