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The critical thinking ability of junior high school students in numeracy learning assisted by augmented reality on the topic of rectangular prisms

Muhammad Ridho Rahman[1], Meryansumayeka[1*]

Universitas Sriwijaya, Palembang, South Sumatera, Indonesia
[*] Correspondence: meryansumayeka@fkip.unsri.ac.id

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Abstract

The increasing focus on computational thinking and numeracy has established critical thinking as a paramount skill in modern mathematics education; however, evidence on how emerging technologies, specifically Augmented Reality (AR), mediate this cognitive process in students remains limited. This study addresses this lacuna by providing an in-depth, mixed-methods analysis of junior high school students' critical thinking performance within an AR-assisted numeracy learning environment, focusing specifically on the challenging domain of rectangular prisms. Employing a descriptive quantitative and qualitative design, this research aims to meticulously describe and evaluate the critical thinking ability of three eighth-grade students selected via purposive sampling across high, moderate, and low initial mathematical ability levels. Data were systematically collected through validated open-ended written tests and follow-up interviews and analyzed using Facione's framework (interpretation, analysis, evaluation, and inference) with a three-tier performance categorization (> 75: high; 60-74: moderate; < 60: low). The analysis revealed a moderate overall level of critical thinking ability (mean score: 66.62). A direct correlation with prior ability was observed: the high-ability student performed highly across all indicators, the moderate-ability student showed proficiency in interpretation and analysis but deficits in evaluation and inference, and the low-ability student remained low across all four facets. These findings significantly highlight the differential influence of prior mathematical ability on higher-order thinking skills, suggesting that while AR effectively facilitates the visualization and analysis components of critical thinking, complementary pedagogical interventions are necessary to enhance complex skills such as mathematical inference.

Keywords: Augmented Reality, Critical Thinking, Mathematics Education, Numeracy Learning, Rectangular Prisms

Introduction

In the 21st century, critical thinking is established as a non-negotiable competency essential for academic success and real-world problem-solving. This skill is consistently grouped with Communication, Collaboration, and Creativity the so-called "4Cs" as foundational for contemporary learners, aligning with the core competencies identified by organizations like the US-based Partnership for 21st Century Skills (Triling & Fadel, 2019; Arnyana, 2019). Given the rapid evolution of technology and globalization, the critical thinking and problem-solving dyad is particularly crucial (Nurhayati et al., 2024). Critically, objective thinking is considered a major goal of developing these higher-level cognitive skills.

Despite this global emphasis, national data frequently highlight a significant deficit in students' mathematical proficiency. For instance, data from the Programme for International Student Assessment (PISA) indicate that Indonesia's mathematics scores are substantially below the global average, scoring 386 versus 487 globally, with a further decline to 379 in 2018 (Anderha & Maskar, 2021). This performance gap underscores the urgent need to enhance problem-solving skills in mathematics, particularly those related to numeracy, as a pathway to improve critical thinking abilities. Providing students with structured opportunities to articulate mathematical ideas, refine their thinking skills, and tackle contextualized problems is a vital pedagogical necessity (Wahidin, 2021).

Critical thinking is formally defined as a reflective process that involves the detailed analysis of observed phenomena to derive logical solutions through systematic reasoning and decision-making (Azis et al., 2021). Ennis (2011) describes this skill precisely as "reasonable and reflective thinking focused on deciding what to believe or do." Furthermore, these Higher-Order Thinking Skills (HOTS) empower individuals to evaluate evidence and accurately interpret inconsistencies or errors in cognitive processes (Bamford, 2019).

In the Indonesian educational context, the "Merdeka Curriculum" advocates for a numeracy-focused learning approach as a core strategy for developing these 21st-century skills (Pasaribu, 2023; Quratul Aini & Adiyono, 2023). Numeracy extends beyond basic arithmetic to encompass the ability to apply mathematical concepts to real-world contexts, including understanding number systems, measurement, and interpreting numerical data to inform decision-making (Susanto et al., 2021). Thus, numeracy learning is a crucial pedagogical tool designed to bridge the gap between abstract mathematical theory and practical application.

The integration of innovative technologies, such as Augmented Reality (AR), presents a powerful opportunity to potentially mitigate these critical thinking deficits. AR technology facilitates student interaction with three-dimensional models of geometric shapes, effectively reducing the cognitive load associated with visualizing abstract concepts (Darmawan et al., 2018). Prior research has established that AR enhances student engagement and conceptual comprehension in mathematics (Hakim & Erlita, 2022) and improves spatial reasoning related to three-dimensional objects (Satria & Prihandoko, 2018).

Despite the utility of AR in fostering interactive and active learning experiences (Meilindawati et al., 2023; Cahyani & Azizah, 2019), research focusing specifically on its impact on the sub-components of critical thinking within a numeracy context remains limited. Most existing literature tends to examine general engagement or spatial visualization.

This study directly addresses this gap by focusing explicitly on students' critical thinking processes as framed by Facione's comprehensive model, which includes the four distinct sub-skills: interpretation, analysis, evaluation, and inference. Specifically, we investigate the critical thinking abilities of junior high school students engaged in AR-assisted numeracy learning on the topic of rectangular prisms. By providing a granular analysis of cognitive performance in this technological context, this research offers a novel contribution to the literature. The findings aim to identify both the strengths and the limitations of AR in developing specific higher-order thinking skills, thereby informing the development of more effective pedagogical strategies that leverage technology to enhance both critical thinking and mathematical numeracy.

Methods

This study employed a sequential explanatory mixed-methods design, integrating both quantitative and qualitative approaches to achieve a comprehensive understanding of students' critical thinking processes. The quantitative approach was utilized to measure and demonstrate the overall achievement levels of students' critical thinking indicators, providing a broad statistical summary. The qualitative approach served to richly describe and interpret students' cognitive responses including their interpretation, analysis, evaluation, and inference during the problem-solving tasks. This integrated methodology was specifically chosen to provide detailed insights into the complex cognitive processes students engaged in while solving geometric problems related to rectangular prisms.

The study was conducted at SMP Negeri 57 Palembang during the 2024/2025 academic year. The study population comprised 29 eighth-grade students from a single intact class (VIII.6). Participants were selected using a purposive sampling technique to ensure the inclusion of students representing varying levels of prior academic ability (high, moderate, and low), which is essential for capturing the spectrum of critical thinking performance. Furthermore, the research utilized three primary instruments: written tests, semi-structured interview guidelines, and AR-assisted learning materials.

Written Critical Thinking Test

The written test consisted of two open-ended problems carefully designed to capture all four indicators of Facione's critical thinking framework: interpretation, analysis, evaluation, and inference. Despite the limited number of items, the problems required multi-step reasoning to assess higher-order thinking. The items underwent rigorous validation by two mathematics education experts and were pilot-tested with a similar grade-level cohort to confirm their readability and appropriateness for junior high school students.

AR-Assisted Learning Material

The intervention utilized the "AR *Bangun Ruang*" application, implemented on students' smartphones. This application, developed by the Teknorat University Indonesia team, was used to facilitate visualization and exploration of rectangular prisms and their nets. The AR component was intentionally integrated into specific tasks outlined in the students' worksheets as known term of LKPD in Indonesia and was not used in isolation. Students worked collaboratively in pairs, sharing one smartphone, under the continuous guidance of the teacher who facilitated the AR-supported problem-solving process.

Interview Guidelines

Semi-structured interview guidelines were developed to elicit deeper insights into students' cognitive strategies, clarify their approaches to the written problems, and triangulate their test responses with their verbal explanations.

Data collection was executed in three distinct stages, namely Preparation and Validation (Research instruments (tests and interview guidelines) were developed and validated by subject-matter experts), Implementation of AR Intervention (The AR-assisted numeracy intervention was delivered across two classroom sessions (totaling 2×40 minutes). These sessions introduced students to the AR application and guided them through collaborative problem-solving tasks on rectangular prisms.), and Data Collection and Triangulation (Immediately following the intervention, students completed the written critical thinking test (40 minutes). In the final stage, semi-structured interviews were conducted with a subset of students (representing high, moderate, and low academic performance) to confirm and elaborate upon the quantitative findings.)

The quantitative data from the written tests were scored using a critical thinking rubric based on Facione's (2023) indicators. Raw scores were converted to a 0-100 scale and categorized into three performance levels: High (≥75), Moderate (60-74), and Low (<60). Descriptive statistics were calculated to summarize the percentage of students achieving proficiency in each critical thinking indicator.

The qualitative data from the semi-structured interviews were transcribed verbatim and subjected to thematic analysis. This involved systematically coding the students' verbal explanations to identify consistent patterns, reasoning errors, and unique strategies related to their problem-solving and critical thinking processes. Finally, for clarity, the specific indicators used for scoring were defined as presented in Table 1.

Table 1. General Indicators of Critical Thinking Ability Based on Facione

General Indicators	Indicator
Interpretation (Ability to Interpret)	The ability to identify and articulate the essential relationships and information needed to express mathematical thoughts or opinions derived from the problem.

General Indicators	Indicator
Analysis (Ability to Investigate)	The ability to investigate and break down complex information, including identifying relationships used to express thoughts or opinions.
Evaluation (Ability to Assess)	The ability to assess the validity of information and select or use appropriate mathematical strategies to solve the problem.
Inference (Conclusions)	The ability to synthesize and identify necessary elements to arrive at a logical, well-justified conclusion.

Ethical approval was secured from the relevant institutional authorities prior to the commencement of the study. Informed consent was obtained from both the participating students and their parents. All data were handled with strict adherence to ethical guidelines, ensuring the confidentiality and anonymity of the participants throughout the research process.

Results and Discussion

The intervention phase of the study was systematically executed across two instructional sessions. A total of 29 students participated in the research sample. Furthermore, each session adhered to a structured pedagogical sequence. The researcher initiated the lesson by establishing classroom decorum, reciting a communal prayer, and explicitly stating the session's learning objectives. To engage students and activate prior knowledge, a preliminary contextual question was presented. Subsequently, the foundational mathematical concepts specifically the definitions, properties, and nets of rectangular prisms were formally explained, along with their practical real-world applications. Following this essential instruction, students were issued the Student Worksheets (LKPD), which contained the two complex, open-ended problems designed to assess critical thinking within the AR-assisted numeracy context.

Figure 1. Display of the AR Build Space Application

Before working on the worksheets, students were guided on how to use the Augmented Reality (AR) application, which had been downloaded to their Android smartphones. Figure 1 shows the AR Build Space Application display. The AR application used was "AR Bangun

Ruang," which is only compatible with Android smartphones. The students were given 40 minutes to complete the LKPD.

In the first session, students began working on the problems in the Student Worksheets (LKPD) related to the basic concepts of rectangular prisms, their nets, and how to calculate surface area and volume with the help of the augmented reality application. This made it easier for students to apply visual illustrations of the geometric shapes. In the second session, students continued working on the same worksheets, focusing on Problem 1 and Problem 2, which involved numeracy questions about rectangular prisms. The students followed a step-by-step approach in solving these problems, starting with the ability to understand, explain, and give meaning to the data or information provided, such as identifying what was known and what was being asked (interpretation). The second step involved identifying relationships and information used to express their thoughts or opinions (analysis), which included drawing illustrations of the problem. The third step was using appropriate strategies to solve the problem (evaluation). The fourth and final step was identifying and obtaining the necessary elements to form a reasonable conclusion (inference).

After the learning sessions and completing two meetings where the students worked on the LKPD, the researcher administered a written test to the students. The results of the study were obtained using a test instrument consisting of two essay questions. Although only two test problems were used, each was designed to capture all four critical thinking indicators. The use of in-depth, open-ended items allowed students to demonstrate their reasoning processes in detail. To strengthen the findings, students' written responses were triangulated with semi-structured interviews, which provided richer data on their problem-solving strategies and helped mitigate concerns about the limited number of test items. This methodological approach aligns with qualitative research principles, where depth of analysis is prioritized over the quantity of test items.

This section may be divided into subheadings. It should provide a concise and precise description of the experimental results, their interpretation, and the experimental conclusions that can be drawn in Table 2.

Table 2. Critical Thinking Test Results of Class VIII.6 Students Based on Indicators

General Indicators	Critical Thinking Ability Indicators	Percentage (%)
Interpretation (Ability to Interpret)	The ability to understand, explain, and interpret data or information presented in a problem.	87.06%
Analysis (Ability to Investigate)	The ability to identify relationships and information used to convey arguments.	61.20%
Evaluation (Ability to Assess)	The ability to apply appropriate strategies to solve a problem.	66.37%

Inference (Conclusions)	The ability to recognize and acquire the necessary elements to draw logical conclusions.	51.72%

This study examined the critical thinking abilities of junior high school students in numeracy learning assisted by Augmented Reality (AR) technology on the topic of rectangular prisms. The results showed that the average critical thinking score of Class VIII.6 students was 66.62, which falls into the "moderate" category. Out of 29 participants, 31.03% (9 students) demonstrated high critical thinking abilities, 55.17% (16 students) were categorized as moderate, and 13.79% (4 students) were classified as low. This distribution reflects varying levels of critical thinking mastery among the students as presented in Table 3.

Table 3. Critical Thinking Test Results of Class VIII.6 Students.

Score Range	Frequency	Percentage (%)	Critical Thinking Ability Category
$80 \leq \text{score} \leq 100$	9	31,03%	High
$50 \leq \text{score} < 80$	16	55,17%	Moderate
$0 \leq \text{score} < 50$	4	13,79%	Low
Total		29	
Average		66,62	
Category		Moderate	

An analysis of student performance across the four critical thinking indicators revealed a differential pattern of achievement, summarized by the following metrics. Furthermore, the interpretation indicator demonstrated the highest achievement, with students scoring 87.06%, placing this skill in the High category. This strong performance indicates students possess robust capabilities in understanding, explaining, and accurately interpreting the data and mathematical information presented within the problem contexts. This finding aligns with the literature, which suggests that strong interpretational skills are fundamental for effective data comprehension (Mira & Sulianto, 2018). The effective use of Augmented Reality (AR) in the initial phase may have contributed to this strength by ensuring clear visualization of the geometric problem context.

Performance on the analysis indicator was 61.20%, categorized as Moderate. This score reflects students' ability to identify key relationships and connect disparate pieces of information. However, the qualitative data revealed specific difficulties, particularly in the process of creating graphical representations or mathematical models of the problems. This deficit suggests an inability among some students to effectively filter and synthesize the relevant numerical and structural information from the problem statement, a common pitfall identified in studies on analytical errors (Rohana et al., 2021).

Students achieved a score of 66.37% for the evaluation indicator, which is classified as Moderate. A key finding emerged regarding the prerequisite skills necessary for successful evaluation: student difficulties in this area were often strongly correlated with deficits in fundamental numeracy. Specifically, several students struggled with basic mathematical operations such as decimal multiplication and percentage calculations. These computational weaknesses often disrupted their ability to effectively evaluate and execute problem-solving strategies, even in cases where the AR technology successfully facilitated the visualization of geometric structures. This observation is consistent with research highlighting how computational weaknesses can severely impede higher-order reasoning (Rahayu & Hakim, 2021). Therefore, while AR supports conceptualization, its effectiveness is partially constrained by students' prerequisite mathematical competencies, suggesting that critical thinking development must be accompanied by reinforcement of foundational numeracy skills.

The inference indicator registered the lowest achievement score at 51.72%, categorized as Low. The primary issue observed was that many students provided numerical answers without providing logical, articulated conclusions, thereby demonstrating difficulty in generalizing and synthesizing their mathematical findings. Facione (2023) emphasized that inference requires students to identify and secure all elements necessary to draw a reasonable conclusion, while Ennis (2011) noted that this skill transcends mere calculation to involve the evaluation of alternatives and justification of decisions. The persistent weakness in inference is likely attributable to a lack of systematic practice in constructing mathematical arguments and formulating generalized statements, which has been previously linked to persistent inference errors among middle school students (Darmawan, 2018). This underscores a significant pedagogical need to explicitly integrate argumentation and conclusion-drawing activities within the AR-assisted learning context.

Figure 2 shows that an analysis of the test and interview answers of students who fall into different ability categories. It shows how the student identified as AK solved question 1.

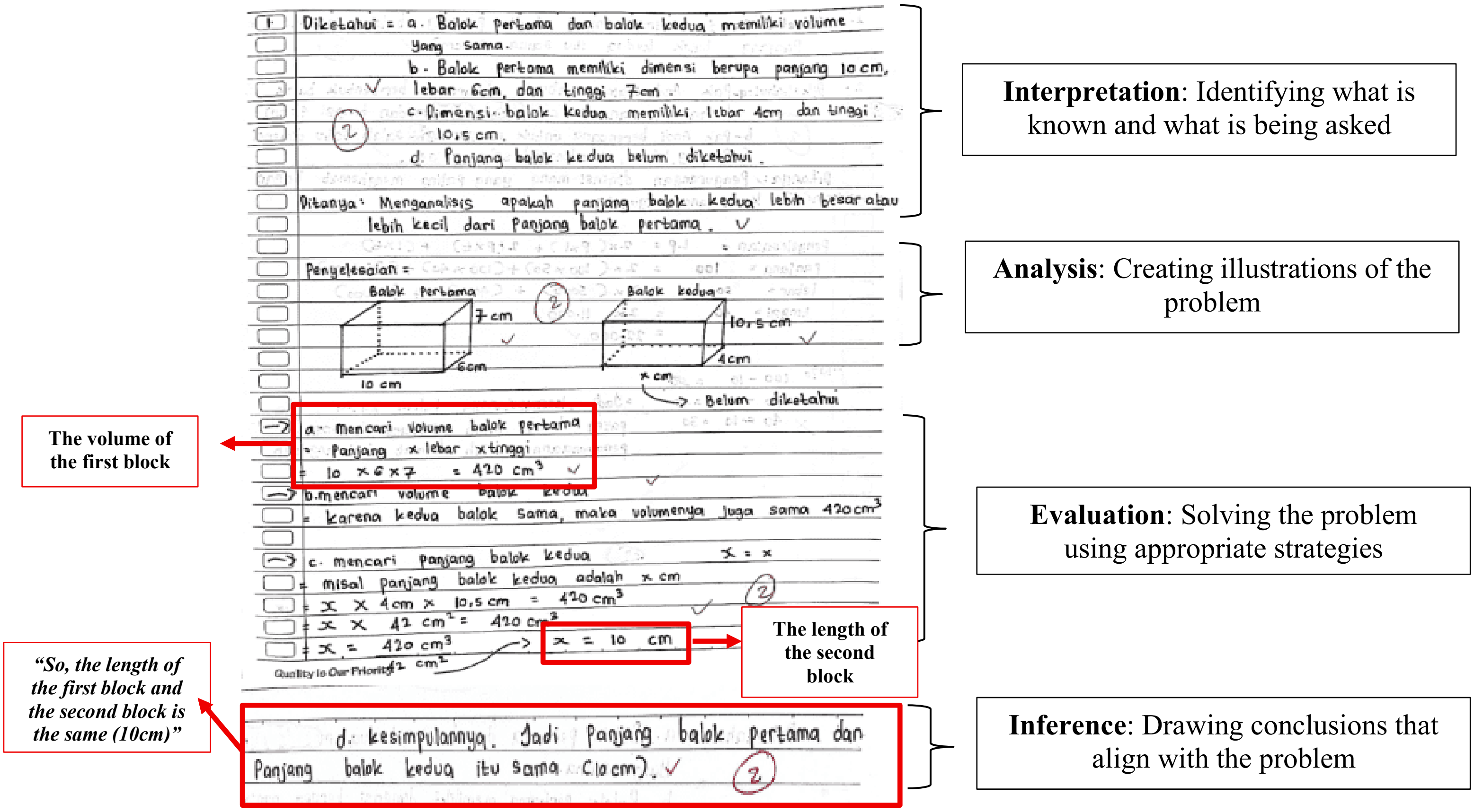


Figure 2. Answer Number 1 AK

For question 1, AK successfully completed all the required steps, from interpretation to inference, correctly solving the problem by following the correct procedures. Meanwhile, another student, IAF, met only three of the indicators: interpretation, evaluation, and inference, but failed to provide an illustration (analysis). The student explained that the lack of focus and time management caused them to omit the illustration during the test.

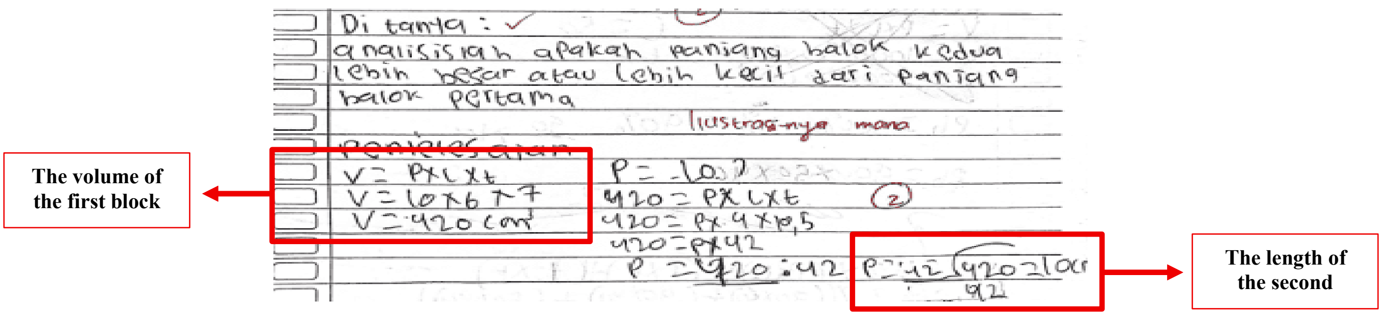


Figure 3. Answer Number 1 IAF

Figure 3 shows that IAF experienced difficulties in answering number 1, this was clarified during the interview process with the related subject. The following are the results of the interview between IAF and researchers

R : *"how do you make an illustration of the question?"*

IAF : *"There is no illustration that I made"*

R	:	*"What are the obstacles?"*
IAF	:	*"Because at that time, I was not focused and not careful enough to draw the illustration. In addition, I could not manage the time to draw it in the last seconds so I did not have time to draw it"*

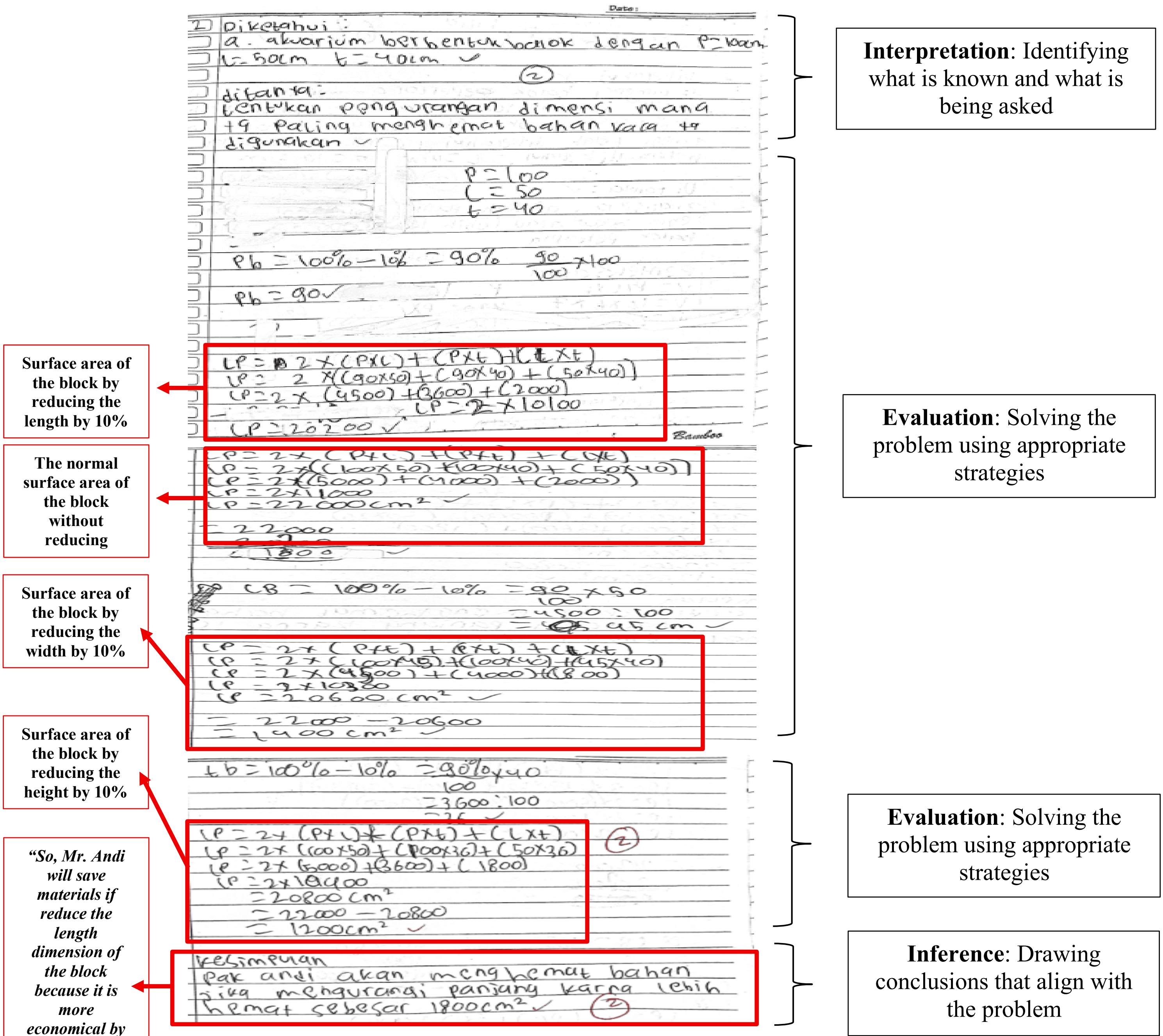


Figure 4. Answer Number 2 IAF

Figure 4 shows IAF answered question 2, IAF again completed three indicators but omitted the illustration step. The student's interview further confirmed that time management and lack of focus were the main challenges in completing this task.

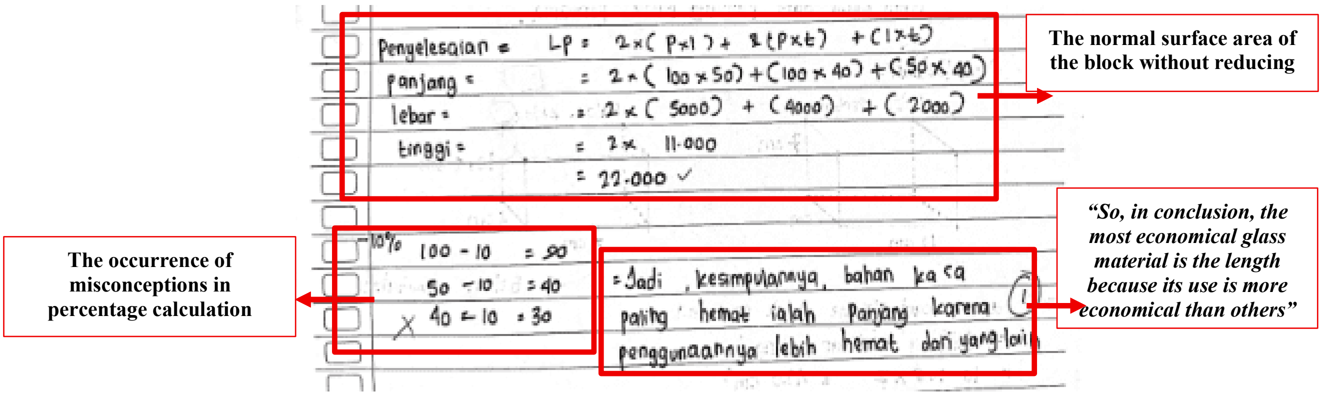


Figure 5. Answer Number 2 AK

Figure 5 shows AK solved problem 2. AK only met the interpretation indicator correctly. The analysis indicator in the form of making an illustration of a picture is not met because it was not answered by the related subject. In addition, the evaluation indicator has been met but is still not quite right because AK is only able to answer finding the initial surface area so that the core answer is not there. In the inference indicator, the subject can write his conclusion even though it is not quite right. There are reasons that AK does not meet several indicators that are worked on in problem number 2, here is a summary of the results of interviews with researchers and related subjects,

R	:	*"How do you create a picture illustration for the question?"*
AK	:	*"I didn't create the picture illustration"*
R	:	*"What are the obstacles?"*
AK	:	*"Because I was only focused on finding the core answer so I forgot to create the picture illustration"*
R	:	*"What about your strategy for solving the core problem of number 2?"*
AK	:	*"By using the surface area formula for a rectangular prism"*
R	:	*"Are you sure about the answer?"*
AK	:	*"I'm not sure, because I only did the initial surface area calculation and was unable to continue finding the core answer"*
R	:	*"What obstacles did you face that prevented you from finding the core answer?"*
AK	:	*"I was confused in calculating the percentage (10%) of the known question so that from that confusion I couldn't continue the answer until the end"*
R	:	*"How do you determine the conclusion even though the core answer is not finished?"*
AK	:	*"I just estimated without considering the core answer."*

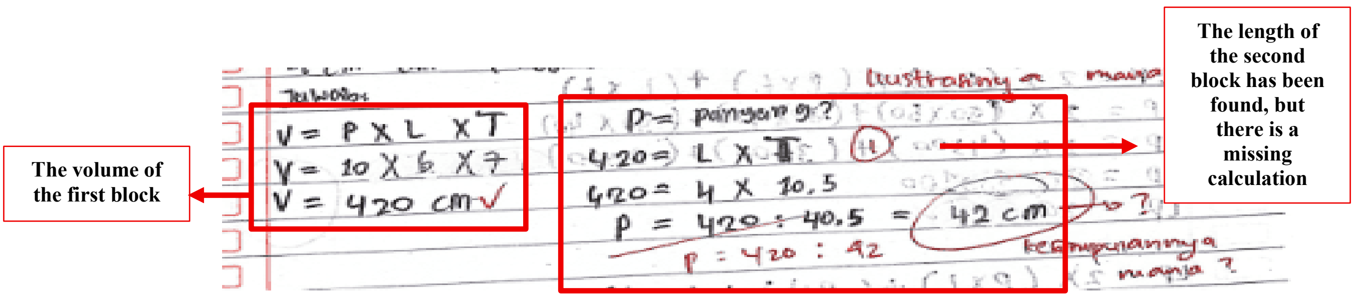


Figure 6. Answer Number 1 MSP

According to Figure 6, the subject with the initials MSP actually knew and understood the problem from number 1, but there were still errors in the work on the 4×10.5 cm section. The answer to the multiplication should be 42 cm. In addition, MSP did not describe the illustration and final conclusion so that the analysis and inference indicators were not met. This was clarified by MSP during an interview with the researcher, the summary of which is as follows,

R : *"How do you make an illustration of the problem?"*
MSP : *"I didn't have time to do the illustration"*
R : *"What are the obstacles?"*
MSP : *"Because I forgot to write it down and didn't focus"*
R : *"What about your strategy to solve the core problem of number 2?"*
MSP : *"By using the rectangular prisms volume formula"*
R : *"Are you sure about your answer?"*
MSP : *"I'm not sure, because the multiplication part confuses me"*
R : *"What obstacles did you face that prevented you from multiplying it?"*
MSP : *"I forgot how to multiply for numbers with commas because in the part of finding the length of the second rectangular prisms you have to multiply the width and height, which is 4×10.5 cm and I'm not sure about the result"*
R : *"What about the conclusion you made?"*
MSP : *"I didn't make any conclusion because time kept running out so I didn't have time to make it, so I went straight to problem number 2"*

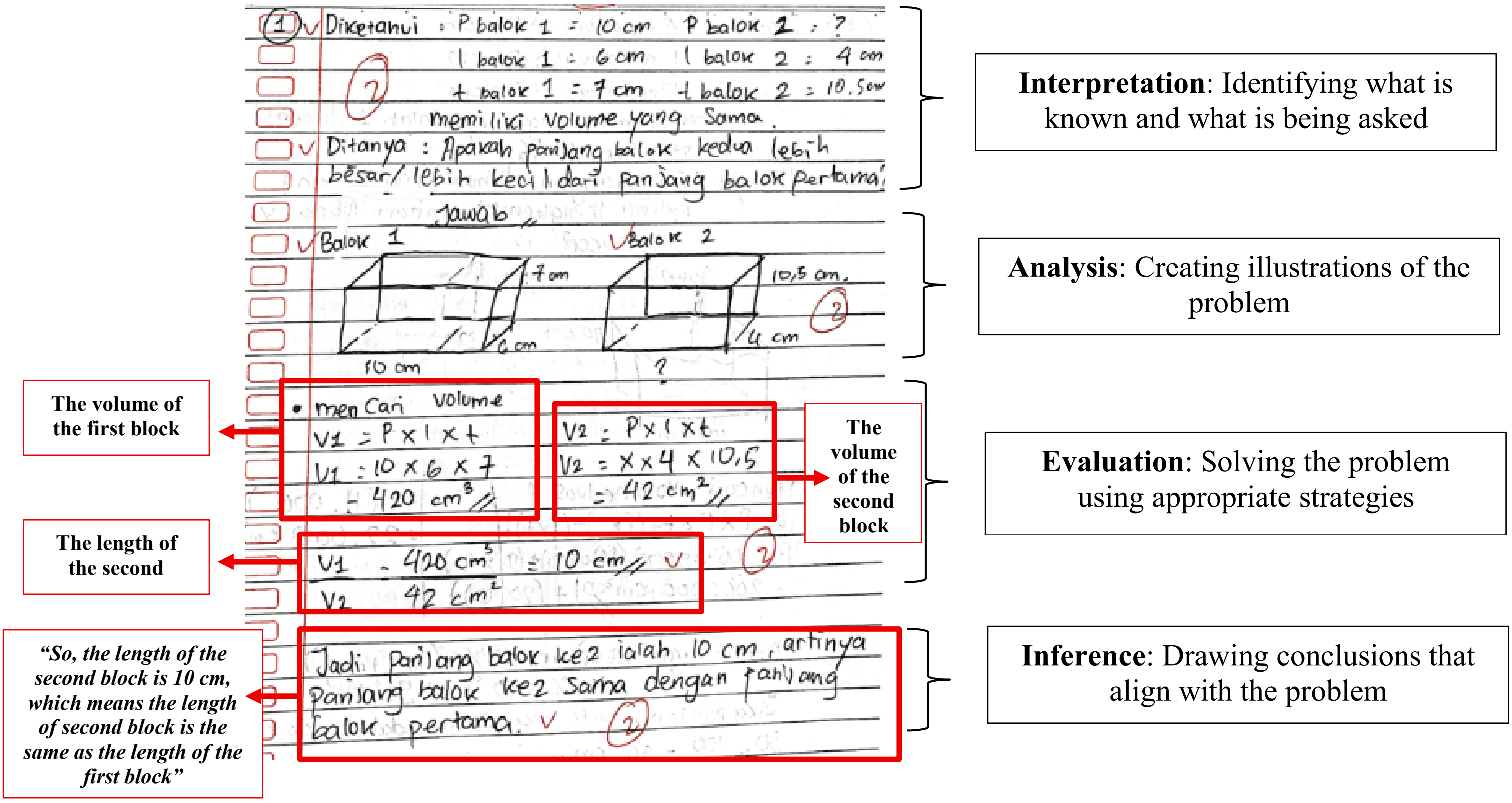
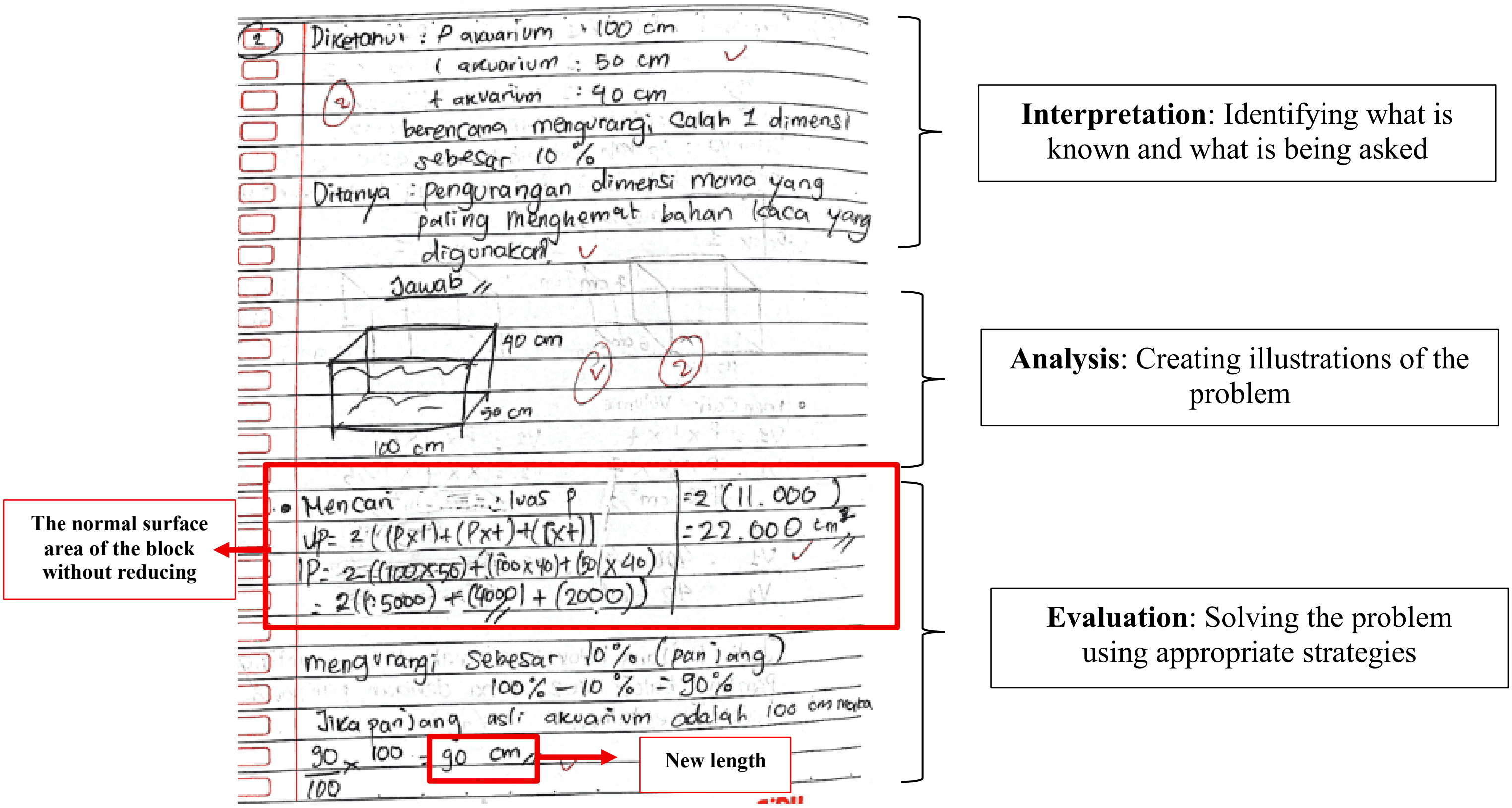


Figure 7. Answer Number 1 ZDA

Figure 7 shows that subjects with the initials ZDA have high critical thinking skills, the related subject has fulfilled the four indicators of critical thinking skills. ZDA can understand the problem well starting from the first step, which is to make what is known and asked (interpretation) of the problem of question number 1 correctly. In the second step, which is to make an illustration of the image (analysis) of two blocks correctly. The third step is to use the right strategy to solve the problem. In the initial stage, ZDA began to calculate the volume of the first block by multiplying the dimensions of length, width, and height that were already known from the problem. Then find the length of the second block using the information on the dimensions of width and height that were already known from the problem and the results of finding the volume of the first block. The related subject has succeeded in finding the length of the second block correctly so that the conclusion made is also correct, namely the length of the first block and the second block have the same size. From the steps of ZDA's work on problem number 1 which are very correct, the four indicators of critical thinking skills (interpretation, analysis, evaluation, and inference) have been met.



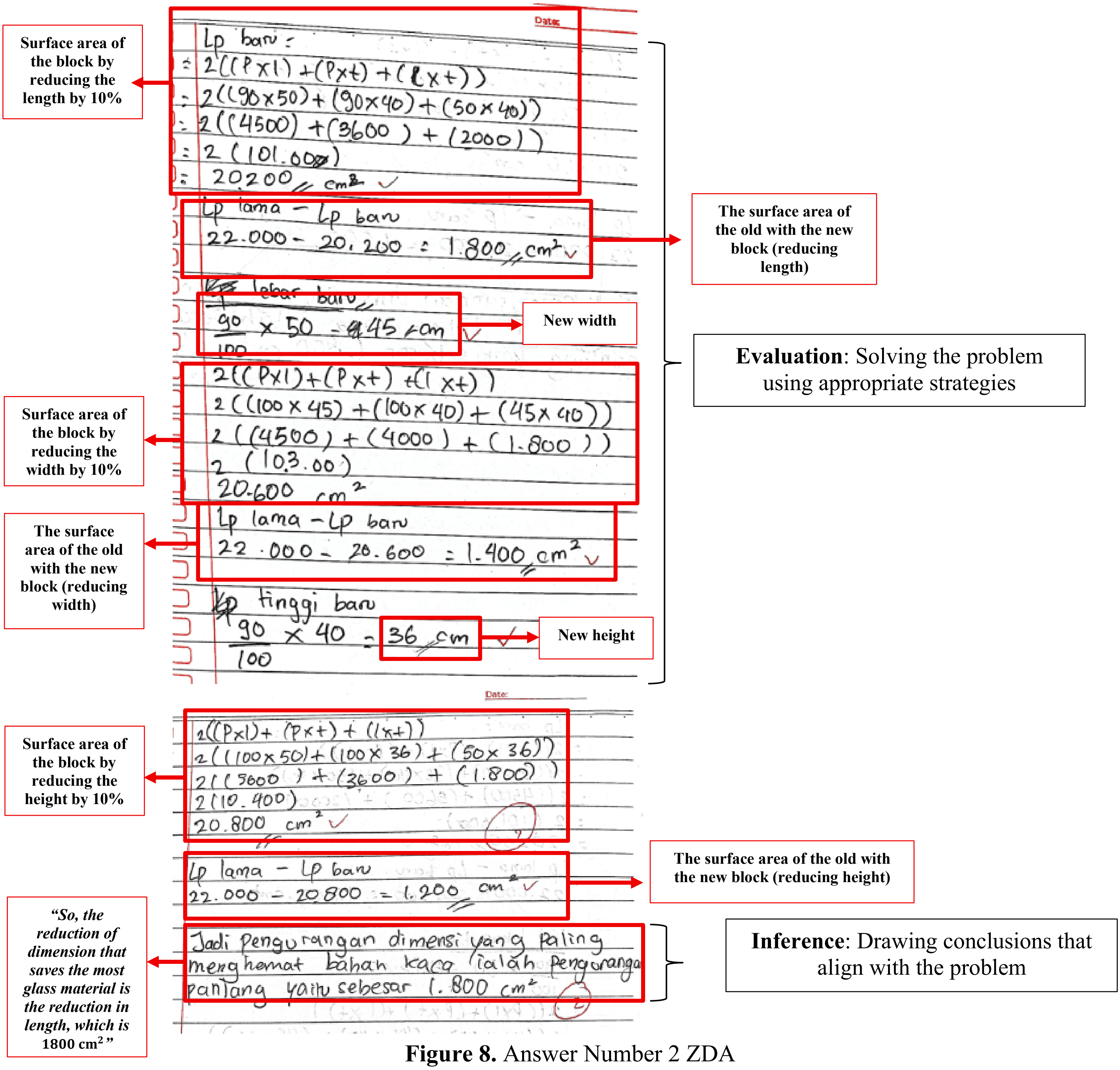


Figure 8. Answer Number 2 ZDA

Likewise in the problem of question number 2 showed in figure 8, ZDA can understand the problem well starting from the first step, which is to make what is known and asked (interpretation) of the problem of question number 2 correctly. In the second step, which is to make an illustration of the image (analysis) of two blocks correctly. The third step is to use the right strategy to solve the problem. In the initial stage, ZDA finds the surface area of the initial block using the known information on the dimensions of length, width, and height. Next, find the new length after a reduction of 10%, then calculate the surface area by replacing the old length value with the new length value. The next step is to find the new width after a reduction of 10%, then calculate the surface area by replacing the old width value with the new width value. The next step is to find the new height after a reduction of 10%, then calculate the surface area by replacing the old height value with the new height value. After getting the three new surface areas, then continue by comparing which dimension reduction is the most effective in reducing the aquarium glass material. ZDA managed to solve the problem very precisely and was able to draw good conclusions, so that all four indicators of critical thinking in problem number 2 had been achieved by the related subjects.

The integration of AR technology significantly enhanced student engagement and understanding. By enabling students to visualize and interact with three-dimensional models of rectangular prisms, AR bridged the gap between abstract mathematical concepts and practical understanding. This aligns with the findings of (Hakim & Erlita, 2022), who highlighted the potential of AR to improve cognitive engagement and mathematical comprehension. Additionally, Meilindawati et al. (2023) found that AR improves visualization skills and makes learning more interactive. However, limitations such as time constraints and students' unfamiliarity with using digital tools for learning were noted in this study. These findings are supported by (Darmawan et al., 2018), who emphasized the need for intensive guidance when introducing new technologies in education.

Several challenges were also identified during this study. Many students struggled with basic calculations, such as handling decimals and large numbers, consistent with findings from (Cahyani & Azizah, 2019), who found that students often make mistakes in basic mathematical operations. Additionally, some students skipped essential steps, such as creating illustrations, which hindered their ability to analyze and infer effectively. Although most students attempted to answer, a lack of accuracy in calculations affected the correctness of the conclusions they drew (Andira et al., 2018). These challenges highlight the need for targeted interventions, such as additional training, to help students improve their critical thinking abilities.

This study demonstrates that integrating AR technology into numeracy learning can be a transformative tool for enhancing engagement and understanding. The study by (Iqliya & Kustijono, 2019) supports these findings, stating that AR-based media effectively train critical thinking skills in cognitive aspects such as interpretation, analysis, evaluation, inference, and explanation, while also enhancing students' imagination. However, its application must be accompanied by effective teaching strategies and sufficient practice time to maximize its benefits. Further research is recommended to explore the use of AR across various mathematical topics and educational levels to validate its broader impact. Additionally, incorporating non-routine and more challenging problems into the curriculum is advised to further develop students' higher-order thinking abilities.

Conclusion

The critical thinking ability of students in numeracy learning assisted by augmented reality on the topic of rectangular prisms in Class VIII.6 at SMP Negeri 57 Palembang falls into the "moderate" category, with an average score of 66.62. The students were able to demonstrate all critical thinking indicators, namely understanding, explaining, and interpreting data or information presented in a problem (interpretation) with a percentage of 87.06%; identifying relationships and information from the problem (analysis) with a percentage of 61.20%; applying appropriate strategies to solve a problem (evaluation) with a percentage of 66.37%; and recognizing and acquiring the necessary elements to draw logical conclusions (inference) with a percentage of 51.72%.

Future researchers are advised to carefully consider the appropriate timing for conducting their studies. It is also recommended to provide brief materials for students to study and administer pretests to assess students' initial abilities prior to the research implementation, both before and after using augmented reality technology. Additionally, it is suggested to present challenging (non-routine) problems related to rectangular prisms to further develop students' critical thinking skills and familiarize them with managing their time effectively during problem-solving.

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