Leveling of Critical Thinking Abilities of Junior High School Students in Solving Geometry Problems

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Abstract – **The capacity for critical thinking varies among individuals and can be viewed as a spectrum from low to high. This qualitative study aimed to explore the development of critical thinking skills in junior high school students tackling geometry problems at SMPN 1 Ambarawa. It assessed components of logic (data, ideas, deduction, perspective) using intellectual norms (clarity, accuracy, thoroughness, relevance, logic, depth, breadth) as criteria. Data collection involved validation, task-based interviews, and written assessments, focusing on ninth-grade students in the 2022–2023 academic year. The findings revealed a range of critical thinking levels: level 2 (moderately critical), level 1 (less critical), and level 0 (minimally critical). Critical thinking is essential for solving geometry problems, and identifying students at different levels can promote equitable learning opportunities, ensuring no one is left behind in developing cognitive skills. These insights can also guide educational policies to enhance intellectual rigor in schools.**

Keywords **– Critical thinking, geometry, elements of reasoning, intellectual standards**

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1. Introduction

The significance of critical thinking in the realm of mathematics education cannot be overstated, as it fosters the development of essential problem-solving abilities in students [1]. This is seen in this way since mathematics is not just about approaching problems the same way, but also about finding new ways to solve problems that students may have never encountered before [2]. Critical thinking encourages students to explore different strategies, question assumptions, and evaluate the solutions they find [3]. Not only that it improves their understanding of the subject matter, but critical thinking also equips them with skills that can be applied in everyday life and various fields of work in the future. In addition, critical thinking in mathematics helps students develop the data analysis and logic skills that are needed in this digital age [4]. The ability to analyze information, identify patterns, and draw logical conclusions is crucial across various contexts, from scientific research to decision-making in business and technology-related professions. Learning mathematics that encourages critical thinking will help students become more numerically intelligent individuals who are better prepared to face challenges in various fields [5].

The emphasis on analytical reasoning in middle school mathematics instruction, especially at SMPN 1 Ambarawa, is undeniably significant. Efforts to integrate this ability into the learning process will provide long-term benefits, both, for students' academic development and for their readiness to face future challenges. One may determine if a person is a competent critical thinker or not by looking at their abilities to interpret, analyze, evaluate, and draw conclusions, to articulate their reasoning and form evaluations, to utilize the capacity for analytical thought, and to become more adept at thinking critically about their opinions [6].

Pupils who possess these six critical thinking skills are much superior to those who can simply perform interpretation, analysis, and assessment [7].

As a result, one could say that people's capacity for critical thinking is leveling out. Everybody has a variable capacity for critical thinking, and this variation can be viewed as a continuum ranging from the lowest to the maximum degree [8]. An individual can be placed on a continuum representing different levels of critical thinking if they are chosen at random. To simplify the classification, the approach used to determine the level of critical thinking ability is a discrete hierarchical classification. This means that the level of ability is grouped in stages such as O, I, II, III IV, or others that are discrete.

A standard or framework for assessing the level of critical thinking is necessary to evaluate students' abilities in critical thinking during problem-solving activities [9]. These standards can be used as a reference to assess how well children are able to think critically and how they are developing as they learn how to solve mathematical issues. An individual can be classified as either an uncritical or critical thinker based on these qualities. There has not been much research, though, on how critical thinking abilities are leveled in Indonesian math problems, particularly in geometry. Consequently, this study aims to formulate approaches that enhance students' capacity for critical analysis when addressing mathematical challenges, especially those related to geometry.

Paul and Elder developed an intellectual standards of reasoning, aspects of reasoning, and intellectual nature of reasoning critical thinking model [10], [11]. To assess and measure students' critical thinking abilities in addressing geometry problems, Paul and Elder's Critical Thinking Model is being used. This model categorizes this these skills based on intellectual standards of reasoning and elements of reasoning. Information, concepts and ideas, inference, point of view, and clarity, accuracy, thoroughness, relevance, logicality, depth, and breadth were the intellectual standards of reasoning that were applied.

Intellectual standards of reasoning are also important in facing the challenges presented by the development of information technology today. This is because technological developments have changed the way information is processed and assessed [12], [13], [14]. Students today are exposed to a flood of information from various sources which may not always be valid. Without adequate critical thinking skills, students are vulnerable to misinformation and disinformation which can affect their ability to make informed decisions [15], [16], [17].

Therefore, education should focus on developing critical thinking as a foundational skill that can help students navigate the complexities of the digital world [18], [19].

Every student has a different level of understanding and critical thinking ability, so it is important to have a structured approach to developing these skills [20]. With leveling in place, teachers can design teaching strategies that match students' ability levels, provide appropriate challenges, and provide the necessary support to reach higher levels of critical thinking [21], [22]. Critical thinking plays an important role in the problem-solving process. Strong critical thinking abilities enable students to recognize issues, evaluate potential solutions, and select the best course of action for resolving such issues [23]. Leveling up critical thinking helps students understand the problem-solving process more systematically and purposefully [24]. This enhances their scholarly capabilities while also equipping them to navigate real-world scenarios that demand analytical reasoning and intricate problem-solving skills.

Enhancing critical thinking abilities can significantly elevate student involvement and engagement in the educational experience [25]. When students are given tasks that match their ability level, they tend to be more motivated and actively participate in class discussions and activities [26]. This fosters a more dynamic and collaborative educational atmosphere, wherein students experience both support and challenge in honing their critical thinking abilities.

Leveling critical thinking also facilitates a more accurate assessment of student development. By understanding the levels of critical thinking ability, teachers can provide more specific and constructive feedback to students. This allows students to realize their strengths and weaknesses, as well as areas that need improvement. Leveling-based assessments can also assist teachers in designing appropriate interventions to help students reach their full potential. The importance of leveling critical thinking in students cannot be ignored. By adopting a structured and systematic approach to developing critical thinking skills, teachers can help students better cope with academic and daily life challenges. Leveling critical thinking not only improves individual skills but also creates a generation that is better equipped. This fosters a dynamic and collaborative learning environment, enabling students to feel both, supported and challenged in the development of their critical thinking skills to address the complexities of contemporary society.

2. Method

The study examined the traits of critical thinking levels using qualitative research methods. The research strategy used was descriptive-qualitative, meaning it made an effort to use qualitative data and qualitative descriptions to explain the events that were the focus of the study (i.e., traits of the critical thinking level).

This study analyzed the intellectual standards of reasoning in relation to the elements of reasoning among students tasked with solving geometry problems, employing the characteristics associated with varying levels of critical thinking ability. The data were produced as written text, numbers derived from the interview findings, and words derived from the interview results. In order to assess the issue, all written and spoken data collected from the people who had been observed, together with any relevant documents, were analyzed as succinctly as possible implementing the qualitative approach used in this study.

The research data took the shape of pupils' critical thinking proficiency levels when tackling geometry issues. The levels were arranged in a discrete manner, namely 0, I, II, III, and IV, based on Paul and Elder's reasoning elements and intellectual reasoning standards. The source of data for this research is the 8th-grade students in the even semester at SMPN 1 Ambarawa for the 2022/2023 academic year. The selected students were divided into 2 groups, namely 8 subjects in pre-research activities and 8 subjects in research activities. In addition to students, this research involved validators. The validators were lecturers of the Department of Mathematics FMIPA UNESA who validated the content and the construct of the draft level of critical thinking skills, problems used during the written test taken from the circle material, and interview guidelines.

The best subject was selected in order to assess pupils' critical thinking skills.

The subject selection technique used the *snowball* method. The method involved selecting subjects on their ability to meet the constructed level of critical thinking and their ability to communicate ideas clearly. Additionally, selection was based on the uniqueness of the answers given by students at each level of critical thinking ability level. The search for subjects starts from the highest level and proceeds towards lower level. These subjects were selected based on the ability in the class from the information gathered from interviews with their mathematics teachers. The criteria for high, medium, and low groups were based on the mathematics ability test and reinforced by the average ability of students in their daily lives.

Initially, the determination of the subject of this study began with the high and medium groups to find the highest level of critical thinking.

No determination of subjects from low group students was made because by itself it made sense that they would enter the low critical thinking level. Determination of subjects from low ability would be done only if there was no low critical thinking level of high and medium ability students.

Each level selected at least two students to serve as subjects in research studies. The selection of two subjects was conducted to ensure that the data analysis method with the *constant comparative* analysis could be done (*the constant comparative method*). As described above, the selection of subjects was carried out by the snowball method; the selection of the next subject was carried out after obtaining the results of the analysis of the previous subject, and when there was no subject occupying a level, it would be checked repeatedly until the subject was obtained.

For the data obtained to be following what was expected, before data collection was carried out, written test questions as auxiliary instruments had been validated by validators. The validation procedure follows the flow presented in Figure 1 below:

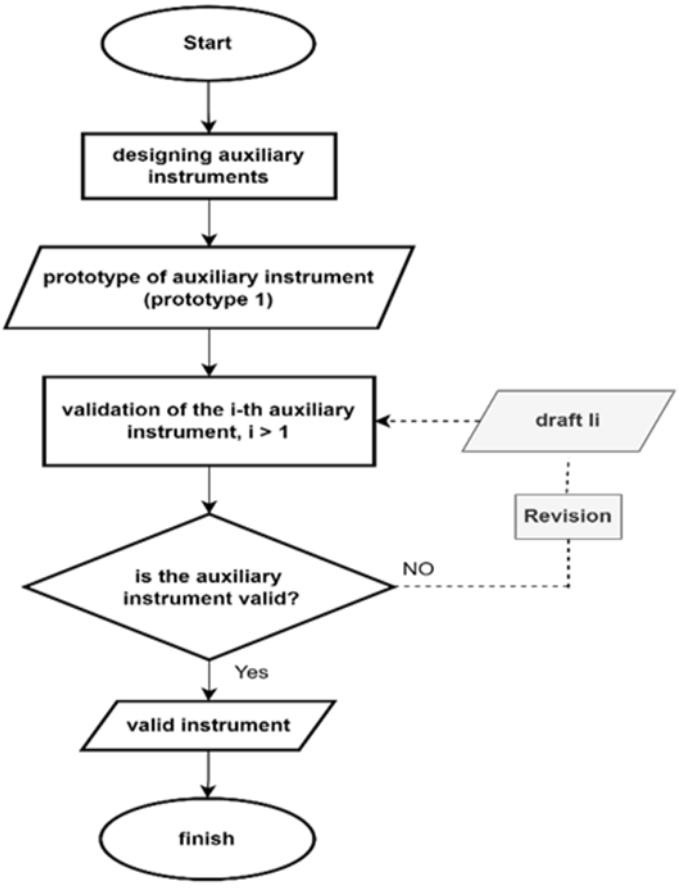

Figure 1. Auxiliary instrument validation procedure

After the auxiliary instrument had been validated, data collection was carried out.

The data collection procedure was presented in Figure 2.

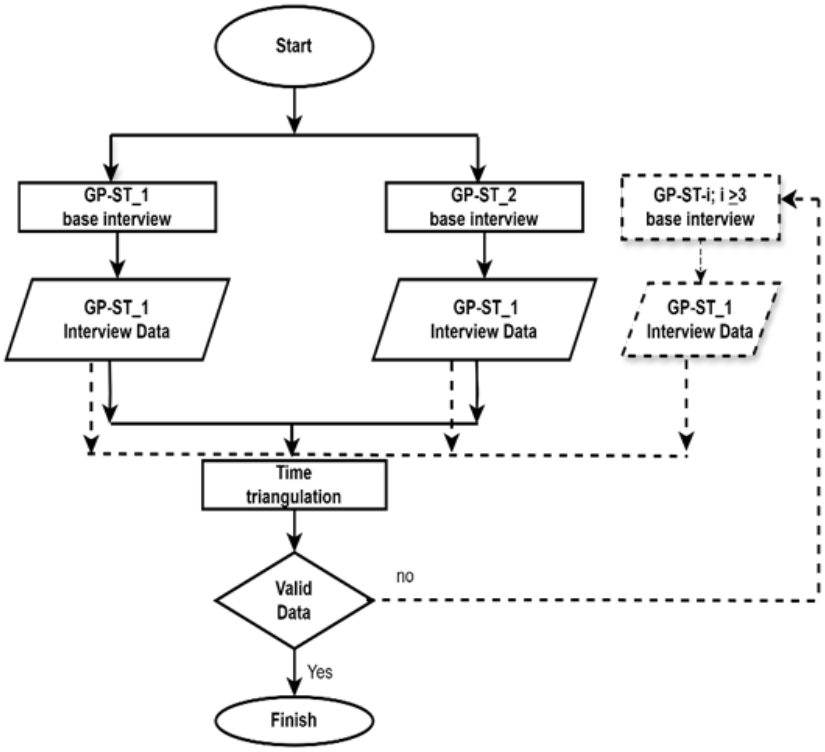

Figure 2. Data collection procedure

As shown in Figure 2, the written test used contained Geometry Problem-Solving Tasks (GP-ST) and was employed to look at the students' degree of critical thinking proficiency. To gather more detailed information and corroborate the results of the written exam, interviews were conducted.

During the interview, a mobile phone was used to record all information. Following the identification of two subjects for every Critical Thinking Ability Level (CTAL), namely IV, III, II, I, and 0, an interview was held with each selected subject. The overall critical thinking level procedure followed the flow as shown in Figure 3.

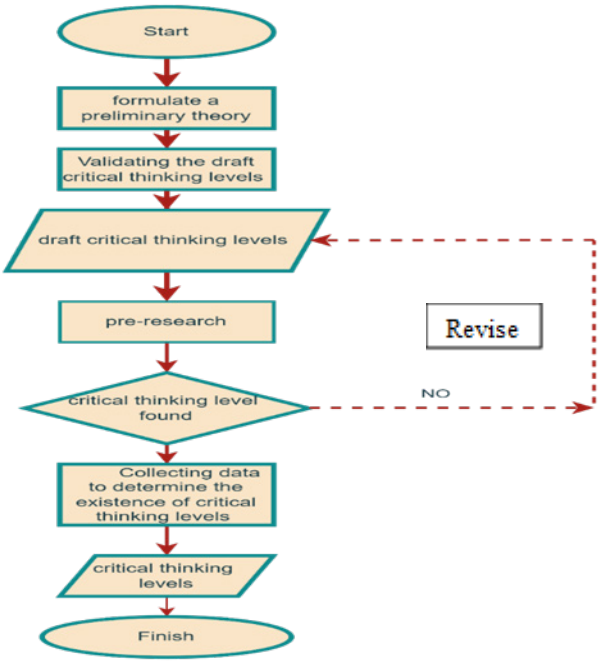

Figure 3. The flow of critical thinking levels

3. Results

The conclusions derived from this study are comprehensively presented in the results section. Appropriate tables and figures should be included to clearly illustrate findings. Tables are particularly useful when precise quantities are important, while figures are effective for displaying data trends or other visual information. This section also discusses the procedure for assessing critical thinking levels, following the steps outlined in Figure 3.

3.1. Developing a Preliminary Theory Based on Theoretical Research Backed by Empirical Evidence

Before developing an early theory (theoretical formulation) known as the draft of the critical thinking level, critical thinking theories and critical thinking assessment standards were evaluated. The draft was used in the classroom to demonstrate pupils' capacity for critical thought.

3.2. Assessing the Content and Construct Validity of the Generated Theory by Having Experts Review the Critical Thinking Level Draft

The research's validity was examined from the perspectives of concept, content, and empirical (internal) validity. The content validity of the materials examined included the appropriateness of the problem's difficulty level, the validity of the theories used as references, and the validity of the tools used to gauge students' critical thinking abilities. Construct validity examined the reasoning and accuracy of the acquired critical thinking level (hypothetical theory). This validity also examined the accuracy in the arrangement of problems such as clear question items, easy to capture the meaning, did not cause multiple interpretations, and ensured that the construct measured critical thinking skills (intellectual standards of reasoning).

Lastly, empirical validity was shown when the level of developed critical thinking followed the observed reality in the field, and the suitability of the problem items to identify aspects of critical thinking.

3.3. Pre-Research to Demonstrate the Validity of Different Levels of Critical Thinking

Pre-research was conducted in class with the material of a circle related to the central angle, circumference angle, arc length, and circular area, and their relationships.

Following the session, a written exam was given to determine the student's level of critical thinking proficiency using the previously created draft of the critical thinking level.

All learners' work was assessed for their reasoning elements using intellectual standards. The *draft of critical thinking level* was used to select research subjects according to the characteristics sought. No data was collected from students in a single class, and students who demonstrated the ability to articulate their thoughts both orally and in writing, with distinctive and unique responses, were selected. Two students were selected as the research subjects for each level of critical thinking ability.

Data collection was undertaken with written tests and task-based interviews, namely interviews related to solving geometry problems done by students. Analysis of the task was done by checking the correctness of the answers to the questions on the self-evaluation sheet made by the students, then looking at the aspects of intellectual standards of reasoning in critical thinking activities in solving problems. Furthermore, the alleged level of critical thinking of these students was determined. If there were still unclear aspects, they were triangulated with interviews. The purpose of these interviews was to ascertain the actual level of critical thinking of students. The task used is presented in Figure 4a and 4b.

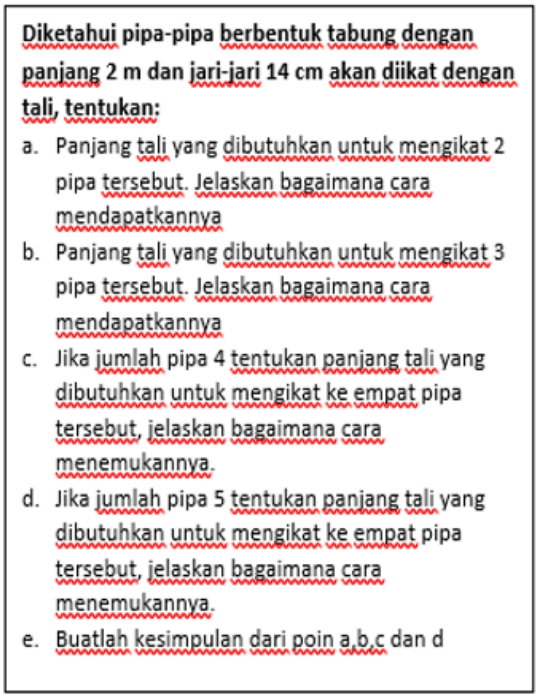

Figure 4a. Geometry problem olving task (GP-ST)

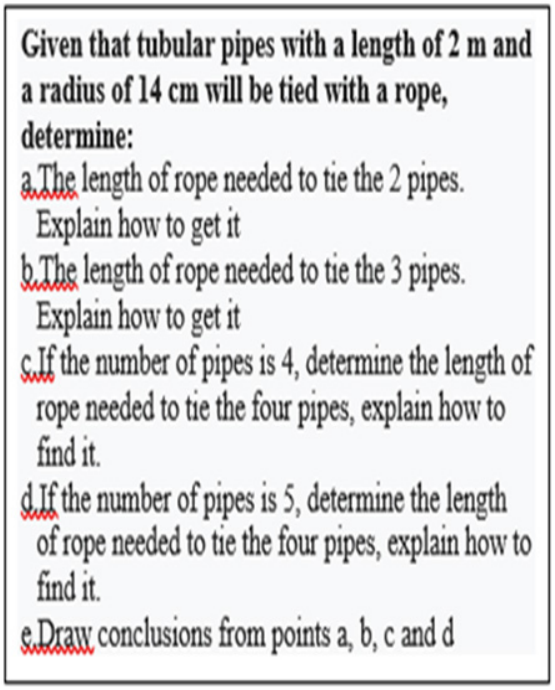

Figure 4b. Geometry problem olving task (GP-ST)

3.4. Revising the Draft of Critical Thinking Level Based on Pre-Research Results

If the results of the pre-research, namely the level of critical thinking skills of students, did not follow the *draft of critical thinking level,* the draft would be revised following the results of the pre-research. It was named an improved draft of the critical thinking level for this new theoretical formulation. The theory is speculative and was created for this investigation.

3.5. Collecting Data to Determine the Existence of the Level of Critical Thinking Skills in Mathematics According to the Hypothetical Theory Created

This data collection was conducted in the research class (VIII-H) utilizing the material of circle. The data collection activities carried out in the research class were the same as the data collection activities in the pre-research class. The *improved draft of critical thinking level* was used for the selection of research subjects according to the characteristics sought. The procedure for selecting research subjects for each level of critical thinking ability and the activities carried out on research subjects were similar to the procedures and activities in the pre-research class.

3.6. Analysis Using the Fixed Comparison Method to Determine the Reliability of the Formulated Critical Thinking Skills

In this research, reliability was fulfilled if the theoretical findings based on a moment of data collection provided identical results (consistent) with the results of the theory that had been formulated previously.

To determine the reliability of theoretical findings, a fixed comparison analysis was conducted [27], which compares a certain category of data with a certain category of other data to obtain a category that has the same fixed characteristics. A category that is fixed is the resulting theory.

Analysis of written problem-solving tasks was conducted by checking the correctness of the answers to the questions on the self-evaluation sheet made by students, and looking at aspects of clarity, accuracy, relevance, logicality, depth, and breadth in critical thinking activities in solving mathematical problems. After that, the alleged level of critical thinking of the subjects was determined. If there were still unclear aspects, they were triangulated with interviews. Data analysis of the interview results was carried out with reduction steps, data exposure, concluding the data that had been collected, and verifying these conclusions.

The results of the interview analysis would be used as a triangulation of the results of the written test analysis. Data analysis was carried out using the *constant comparative* method.

The draft levels of critical thinking skills were developed intuitively based on Paul and Elder's Critical Thinking Model and are listed in Table 1.

Table 1. The draft of intellectual standard of reasoning of students in solving geometry problem

Elements Reasoning	ISR	CTAL 3	CTAL 2	CTAL 1	CTAL 0
Information	Clear	√	√	√	-
	Exactly	√	√	√	-
	Research	√	√	√	-
	Relevant	√	√	√	-
Concepts and ideas	Clear	√	√	√	-
	Exactly	√	√	-	-
	Relevant	√	√	-	-
	In	-	-	-	-
Conclusion	Clear	√	-	-	-
	Logical	√	-	-	-
Angles View	Clear	√	-	-	-
	Extensive	-	-	-	-

ISR: Intellectual standard of reasoning
CTAL: Critical thinking ability level

The students were divided into levels based on the established features, which were taken from the draft critical thinking level utilized in the pre-research class.

Consequently, none of the pupils were in the CTAL 4 and 3. However, some students were included in CTAL 2, 1 and 0. The findings are presented in Figure 5.

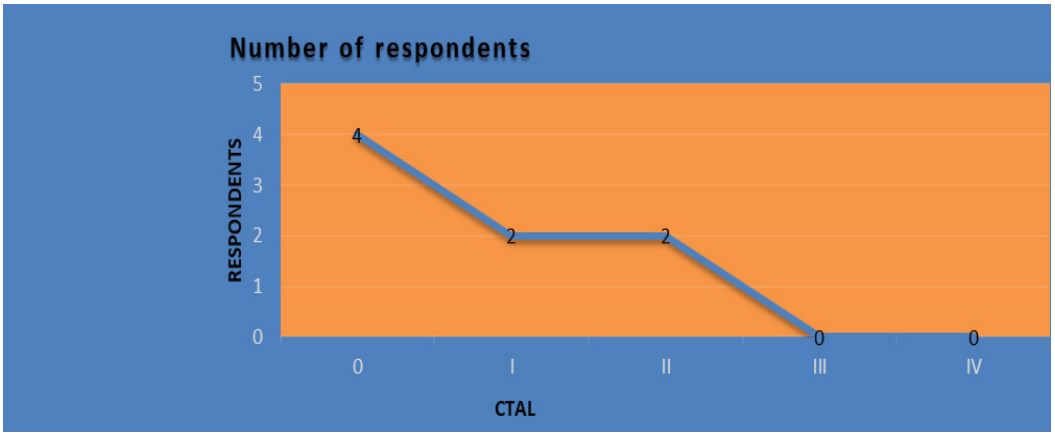

Figure 5. Fulfillment of critical thinking ability level

According to the figure 5, there were no students who were eligible with criteria close to CTAL IV and 3. This was because students did not fulfill the aspects of being careful when receiving information, and logical aspects of problem inference. However, some subjects had criteria close to CTAL III-IV. The students in these criteria did not meet the standard of the element of reasoning concepts and ideas and the intellectual standard of reasoning the depth aspect. As for students in the criterion CTAL II, the standards for the element of reasoning with the logical standard as well as the element of reasoning with points of view standard were not met.

CTAL III-II were later improved to CTAL II since junior high school students' ability to solve mathematical problems might vary depending on several factors, including the quality of education, teaching methods, and students' backgrounds.

In the study's results, some students were categorized into CTAL II-I, since they did not meet the criterion of CTAL II for the elements of reasoning concepts and ideas, and the elements of reasoning with points of view. However, it also could not be categorized as TKBK 1 since they met the criteria for the elements of reasoning information, even though they did not meet the criteria for the elements of reasoning inference, namely logic.

This CTAL II-I later in the improved draft became CTAL 1. There were no students categorized as CTAL 1 according to the draft. This is because all intellectual standards of reasoning in the elements of reasoning information were met, and logical intellectual standards in the elements of reasoning inference which were initially less logical became illogical and unclear.

Based on the reality in the pre-research classroom, the draft level of critical thinking skills was revised (improved) according to the real condition. The revised draft of the critical thinking skill level is shown in Table 2

Table 2. Improved draft of intellectual standard of reasoning

Elements Reasoning	ISR	CTAL 2	CTAL 1	CTAL 0
Information	Clear	√	√	-
	Exactly	√	√	-
	Research	√	√	-
	Relevant	√	√	-
Concepts and ideas	Clear	√	√	-
	Exactly	-	-	-
	Relevant	√	-	-
	In	-	-	-
Conclusion	Clear	-	-	-
	Logical	-	-	-
Angles View	Clear	-	-	-
	Extensive	-	-	-

ISR: Intellectual standard of reasoning
CTAL: Critical thinking ability level

4. Discussion

The improved draft of critical thinking level was applied to the research class and obtained due to the fact that most students were at CTAL 0 and CTAL 1, and the leveling was only up to CTAL II. The features in the revised draft matched those of every degree of critical thinking proficiency among the research class students. Thus, the level of critical thinking ability of SMPN 1 Ambarawa students is listed in Table 3. According to [28] there are 6 levels of critical thinking skills as follows.

4.1. Unreflective Thinking

Unaware of the importance of thinking in life, thinkers are unable to evaluate their own thinking and cultivate a variety of thinking techniques. They consequently fail to recognize thinking as a process that incorporates reasoning. They do not know what criteria should be used to evaluate thinking, such as accuracy, rigor, relevance, clarity, and precision. Thinkers understand the importance of thinking in life, that thoughtful, intentional thought is necessary for good thinking, and that they frequently make mistakes in their thinking but are unable to pinpoint the exact causes of these errors. This level of thinker's capacity for thought is restricted.

4.2. Beginning Thinking

Thinkers begin to modify some of their thinking skills but have limited insight. They lack a systematic plan to improve their thinking. Novice thinkers often rely on the opinions and views of others, as they do not yet have the confidence or skills to make independent judgments. Novice thinkers often have a limited understanding of complex concepts or issues. They may only see the surface of the issue without realizing the deeper nuances or implications [27].

4.3. Practicing Thinking

Thinkers analyze their thoughts actively in some areas but they still have limited insight into the level of deep thinking. In addition, according to Fujii [29], this level of thinking begins to understand concepts in greater depth and can see the connections between various ideas and information. They can connect seemingly unrelated concepts and see the bigger picture.

4.4. Advanced Thinking

Active thinkers examine their ideas and possess significant understanding of topics at a profound level of cognition.

They are not yet able to regularly think in all aspects of their existence at a higher level, though. Advanced thinkers can analyze information deeply and comprehensively. They can break down complex problems into smaller parts to understand the structures and relationships that exist within them. They can also integrate information from multiple diverse sources and structure it into a cohesive understanding. Advanced thinkers can often generate new insights and innovative solutions from existing information and make informed judgments by considering all relevant evidence and viewpoints. Their decisions are based on rigorous analysis and careful consideration. Lastly, they can continuously look for ways to improve and hone their thinking skills, and they learn from their mistakes and previous experiences.

4.5. Master Thinking

Thinkers deeply internalize fundamental concepts of thinking skills. Critical thinking is a deliberate process that employs a high degree of intuition. They judge thoughts on clarity, precision, rigor, relevance, and logicality intuitively. Excellent thinkers are capable of very deep and incisive analysis. They not only do understand all aspects of a problem but can also identify broader and deeper implications of the available information. They show a high level of creativity and innovation in problem-solving. Excellent thinkers can develop new approaches and solutions that have never been thought of before. They can integrate highly complex information from multiple sources and domains to form a comprehensive and innovative understanding.

This leveling of critical thinking skills compared to Elder and Paul's Levels of Critical Thinking Skills is presented in Figure 6.

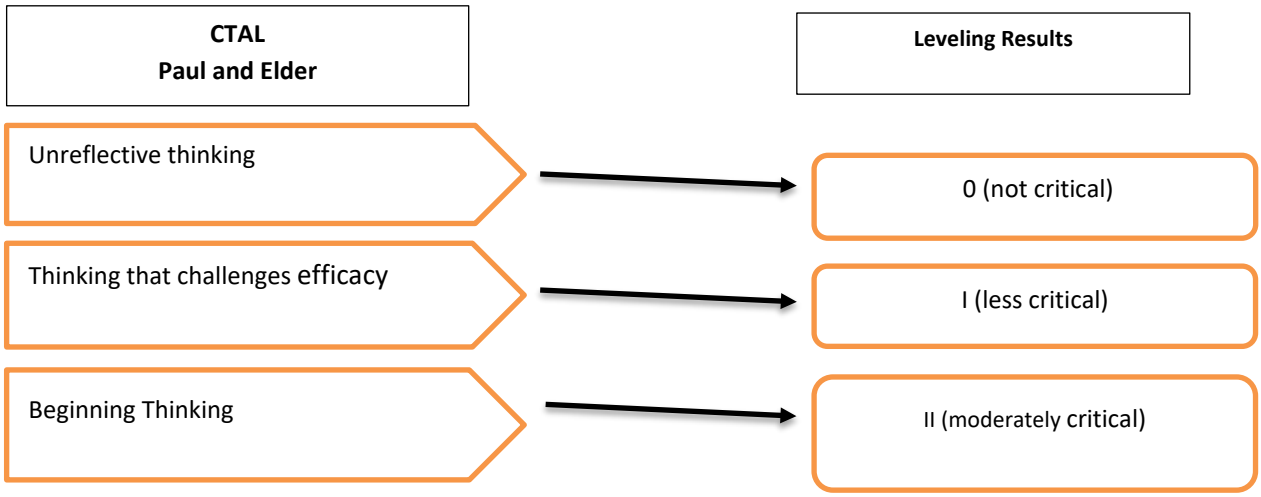

Figure 6. Critical thinking scoring results of junior high school learners

CTAL 0

Any way of thinking that is not represented in Elder and Paul's TKBK is equivalent to TKBK 0 (not critical). This is viewed in this light because students did not use intellectual standards of reasoning or reasoning components (standards of judgment). Additionally, the students acquired a wide range of cognitive abilities, including problem definition, relationship recognition, and knowledge recognition. These skills have not, however, yet been put to use in the form of methodical and logical reasoning for solving mathematical puzzles. Students' failure to meet all intellectual requirements of reasoning in the areas of reasoning information, concepts and ideas, inference, and point of view demonstrated this reality.

CTAL I

Since thinking abilities have been cultivated by pupils at this level, might be compared to hard thinking. The thinking ability is still restricted, though, to the extent that it can only be used to explore data that satisfies the clear standard of intellectual reasoning as well as to investigate and grow aware of thoughts and ideas that do the same. The students in the study used concepts improperly and had unclear and illogical points of view and reasoning when solving problems, even though they were aware of their cognitive deficiencies.

CTAL II

CTAL II can be compared to starting thinking since children at this stage start to adjust their modes of thinking, which include problem identification, relationship recognition, searching for pertinent and appropriate concepts, and employing analogies to solve problems with limited understanding. Students' thinking nevertheless failed to satisfy the required criteria of clarity, and their point of view was narrow and unclear (e.g., by using analogies that were not developed in accordance with the situation given in the problem being answered). The use of analogies namely, the comparison between problem-solving on the self-evaluation sheet and in-class learning evidences that the students lacked systematic planning when it came to solving non-routine problems, even though the problems required consideration of some distinct information.

CTAL III

At this level, pupils actively critique their thinking, which is equivalent to practicing thinking. They have the ability to utilize analytical thinking to solve mathematical issues and to think critically about the components and intellectual standards of reasoning. Additionally, they understand the critical measures to follow in order to solve the problem—in this instance, the point of view is obvious. In order for the information and inference components to meet all criteria, the concept and idea elements to meet most standards, and the viewpoint element to meet most standards, the students also understood how to apply the intellectual standard of reasoning as the standard of assessment.

CTAL IV

TKBK 4 is in line with advanced thinking because students have thought systematically and formed an organized problem-solving plan. This can be seen in the information element and the elements of concepts and ideas that were met by students (except the standards in the elements of concepts and ideas were not met) in exploring things that are considered to be used to solve the problem. A clear point of view in the sense that students have planned the solution with a clear strategy also meets the standard. Students can think systematically and make reasoning about the steps of work that are clear and logical. The reasoning made has met the clear and logical standards showing that students at this level have been able to assess the quality of their thinking so that they can sort out which reasoning cannot be used and which reasoning can be used.

CTAL V

CTAL V also contains superior thinking because students have conscious critical thinking. This can be seen in the reasoning made that meets the clear and logical standards. Students use high intuition to find the concepts used and explore information. Thinkers at this level have in-depth knowledge related to information and concepts that can be employed to resolve mathematical issues. This is indicated by the fulfillment of all standards on the information element and the fulfillment of most of the standards on the concept and idea elements (deep standards were not met).

5. Conclusion

Ultimately, the level of critical thinking ability of students of SMP \N 1 Ambarawa in solving geometry problems was up to the level of critical thinking ability II (quite critical) and not up to the level of critical thinking ability III and IV (critical and very critical). When tackling geometry issues, pupils at SMPN 1 Ambarawa demonstrated a degree of critical thinking skills that included three levels: level II (quite critical), level 1 (less critical), and level 0 (not critical). Table 2 lists the attributes of each degree of critical thinking proficiency.

Furthermore, this study found that the level of critical thinking skills of students is only up to a fairly critical level and most students show low critical thinking skills. Therefore, it is recommended that further research discuss efforts to improve the critical thinking skills of junior high school students in solving geometry problems. In addition, further research needs to be done at SMPN 1 Ambarawa to stabilize the results of the critical thinking ability of students in solving geometric problems. This further research should use a variety of critical thinking ability measurement tools and a fairly long research time.

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