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Cognitive Growth Learning Model to Improve the Students' Critical Thinking Skills

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Abstract. *The ability to think critically and mathematically is strongly needed so that the students are able to face the challenges of 4.0 industrial revolution. By thinking critically, they are expected to be more adaptive in finding solutions to each problem. This study aims to identify the students' mathematical critical thinking skills in solving differential calculus problem solving based on some indicators of mathematical critical thinking skills in learning using cognitive growth model. This is a Classroom Action Research (CAR) which was caried out within four weeks in the odd semester of academic year 2018/2019. The subjects of this study were the first-year students of the Mathematics Education Program in one of higher education institutions in Magelang, Central Java who took the Differential Calculus course. Data collection techniques in this study were test, observation, and interviews. The test results were then analyzed quantitatively, and the indicators of critical thinking skills in each question were also described. Based on the results of the study, it can be shown that about 30% students who begin to think critically is initiated by achieving the indicator of analyzing the arguments. However, not all students who begin to think critically are also able to draw conclusions precisely through deductive and inductive reasoning. There are only five or 16.67% who have been able to draw conclusions correctly.*

Keywords: *Differential Calculus, Mathematical Skills, Critical Thinking Skills, Cognitive Growth Model*

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Introduction

In current 4.0 Industrial Revolution era, someone must have 21st century abilities or skills, namely critical thinking and problem solving, creative and innovative, communication, and collaboration. The world of education, including universities, is demanded to be able to equip their students with 21st century skills to be able to compete or survive well. In addition, skills are also needed to find, manage, and convey and use information and technology. Cheng (2017) stated that 21st century skills and literacy include basic skills, technology skills, problem solving skills, communication skills, critical and creative thinking skills, information or digital skills, inquiry or reasoning skills, interpersonal skills, and multicultural and multilingual skills.

One of the skills that the students need to master is Critical Thinking Skills. Critical thinking is one of the stages of higher-level thinking. Costa (as cited by Liliasari, 2001) categorized complex thinking process or higher-order thinking into four groups which include problem solving, decision making, critical thinking, and creative thinking. In addition, Krulik & Rudnick (1995) argued that basic thinking, critical thinking, and

creative thinking are part of reasoning in order to think well. Therefore, if the students want to think critically in mathematics, they must understand mathematics itself well. They can develop critical thinking skills when dealing with mathematical problems, identify possible solutions, and evaluate the results (Su, Ricci, & Mnatsakanian, 2016).

Ennis (1993) stated that there are six basic elements in critical thinking, namely focus, reason, inference, situation, clarity, and overview. Besides the formulation from Ennis, there are also other indicators formulated by Perkins & Murphy (2006) that critical thinking goes through four important stages, namely clarification, evaluation, conclusion and strategy. Critical thinking is a process and learning mathematics also emphasizes the process not the result. This is in line with Paul & Nosick's statement (Palmer, 2007) which defined critical thinking as an intellectual process for analyzing, applying, synthesizing or evaluating information based on observation, experience, reflection, reasoning or communication process.

Although the formulations above have some differences according to the experts' point of views, but they have a consensus regarding the indicators of critical thinking skills (Facione, 2013). Based on this consensus, they concluded six cognitive skills in critical thinking, including: interpretation, analysis, evaluation, inference, explanation, and self-regulation (Facione, 2013). Lai (2011) also synthesized the indicators of critical thinking by not reducing the essence of the indicators already formulated by the experts previously. The formulation of critical thinking indicators includes the skills of analyzing, synthesizing arguments, evaluating information, drawing conclusions using deductive and inductive reasoning, and solving problems. Lai (2011) also stated that in building critical thinking habits, the teachers must use open-ended assignments, authentic problems, real-world contexts, and unstructured problems so that the students must remember or restate the information they have learned. The indicators of critical thinking skills used in this study are adopted from Perkins & Murphy, including analyzing arguments, evaluating information, synthesizing evidence, and drawing conclusions using deductive and inductive reasoning.

However, some research shows that the students are still rarely able to reach higher levels of thinking. The results of Zetriuslita, Ariawan, & Nufus (2016) described the ability of the students to solve integral calculus problem compilation based on the indicators of mathematical critical thinking skills and levels of mathematical skills (high, medium, low). The students already have the ability to generalize, but they are not yet able to identify and justify the concepts. They also do not have the ability to analyze or evaluate an algorithm. The results of the study are supported by research Safrida, Ambarwati, & Adawiyah (2018) who showed that of the 30 students whose critical thinking skills were being tested, only four of them who succeeded in reaching the four indicators, namely analyzing arguments, evaluating information, synthesizing evidence, and drawing conclusions.

An initial study on mathematics education students at one of the higher-institution in Magelang, Central Java, Indonesia showed that the skills of the first semester students in the academic year 2018/2019 was still low. It was shown that out of 30 students, only five of them who were able to analyze the arguments well when solving some problems in Differential Calculus course. In addition, only 3 students were able to synthesize evidence and none of them able to draw the conclusions precisely. This shows that there are no students who are able to reach the four indicators of critical thinking skills.

Cognitive Growth Model is one of the learning models that can be used to improve critical thinking skills (Chasanah, 2019). According to Piaget (Joyce & Weil, 2008), the Cognitive Growth model in learning is intended to improve the thinking skills (cognitive). This learning model is based on the theory of development that was coined by Jean Piaget and the moral development of Lawrence Kohlberg. In Piaget's concept,

there are two things that become important aspects of cognitive development, namely schemes and adaptation. Schemes are intellectual concepts or structures that are embedded in the mind of a child. It can also be said that a scheme is a program or strategy that individuals use in interacting with their environment

The use of this scheme is called adaptation, meanwhile adaptation can be divided into assimilation and accommodation. When the experienced experiences match the schemes they have, this is called assimilation. If it is not suitable and then creates a new scheme, then this is an accommodation. Accommodation is a change in concept (scheme) to match the new experiences experienced. Based on the views of Jean Piaget and Lawrence Kohlberg, the presentation of learning must be adjusted to the level of thinking or moral reasoning of the learners and can encourage their level of thinking or moral one level higher (Joyce & Weil, 2008). Therefore, the Cognitive Growth model fits in with the stages of learning development and improves the students' critical thinking skills. The syntax of cognitive growth learning refers to Joyce's opinion is described as follows:

Table 1. Syntax of Cognitive Growth Model

Phase	Descriptions
Phase 1 *Confrontation with stage-relevant tasks*	Integration of problems according to the stages, students' orientation on the problems to be studied. It is intended that the students are ready to think more critically in the next learning phase
Phase 2 *Inquiry*	Organizing the students to raise their sensitivity and critical thinking skills; being active in group formation activities in a class
	Analyzing and evaluating the process; the learning process that has been implemented is evaluated or reflected in order to imrpove the learning activities, while the results are criticized and discussed together in the class
Phase 3 *Transfer Phase*	Integration of problems according to the stages, students' orientation on the problems to be studied. It is intended that the students are ready to think more critically in the next learning phase

This study aims to identify the mathematical critical thinking skills of the students in solving problems of differential calculus topic using the cognitive growth model. The contribution of this research is to provide additional knowledge about learning mathematics, especially to improve the ability to think mathematics critically. Besides, it is also expected to provide inputs to the educators to innovate more through the learning using cognitive growth model.

Research Methods

This was a Classroom Action Research (CAR) conducted within four weeks, followed by identifying the students' critical thinking skills. The subjects of this study were 30 first semester students from one of higher education institutions in Magelang, Indonesia. The research instrument consisted of test questions, rubric indicators of critical thinking skills, and interview guidelines. The Critical Thinking Ability Test (CTAT) is used to determine the students' critical thinking skills in mathematics based on the indicators of analyzing arguments, evaluating information, synthesizing evidence, and drawing conclusions. The CTAT instrument was validated through the assessment.

The CTAT instrument consisted of three questions in each cycle. In the first cycle, the CTAT question took the topic of inequality of concept real number. Meanwhile, the second cycle CTAT questions were about the inequality of real numbers with absolute signs. For the third cycle, CTAT was more about in the domain and range of function. The following were the examples of CTAT problems in each cycle.

A question of cycle I

Determine the set of inequality resolutions $\frac{1}{x+1} \geq \frac{3}{x-2}$!

A question of cycle II

In new cars, the number of kilometers per liter depends on how they are used, whether they are often used for long or only for short distance travel (within the city). For a particular car brand, the number of kilometers per liter ranges around 2.8 less or more than 12 km / L. What is the range of km / L from the car?

A question of cycle III

It is known $f(x) = \sin 2x$ dan $g(x) = \sqrt{x-2}$. Determine D_f, R_f, D_g, dan R_g!

Table 2. Mathematics Critical Thinking Assessment Rubric

No.	Mathematics Critical Thinking Criteria	Assessed Aspects		
		0	1	2
1	Analyzing the arguments	The students are not able to explain the terms used in opinion correctly	The students are able to explain the terms used in opinion less correctly	The students are able to explain the terms used in opinion correctly
2	Evaluating the information	The students are not able to mention what information is known and asked correctly.	The students are able to mention what information is known and asked less correctly.	The students are not able to mention what information is known and asked correctly.
3	Synthesizing the evidence	The students are not able to provide evidence that supports the conclusions correctly	The students are able to provide evidence that supports the conclusions less correctly	The students are able to provide evidence that supports the conclusions correctly
4	Drawing conclusions	The students use inappropriate reasons during the process of drawing conclusions	The students use less appropriate reasons during the process of drawing conclusions	The students use fully appropriate reasons during the process of drawing conclusions

To measure the students' critical thinking skills in solving CTAT problems, the researcher arranged a rubric to analyze the achievement of critical thinking indicators as

presented in Table 2. The students' test results were then analyzed using critical thinking indicators to determine the percentage of indicators achievement in each question. The test results were also supported by interviews with the research subjects.

Results and Discussion

The implementation of the learning using *Cognitive Growth* model on each cycle are described in Table 3. Then, Table 4 shows the learning activities in each phase of cognitive growth learning models.

Table 3. Each Cycle's Activities in the Classroom Action Research

No	Stage	Activities
1.	Cycle I	a. Identification of problem b. Planning I c. Implementation of the Learning using *Cognitive Growth* model and Observation d. Topic: Inequality of real numbers on fraction forms e. Reflection
2.	Cycle II	a. Planning II (Results of reflection on Cycle I) b. Implementation of the Learning using *Cognitive Growth* model and Observation c. Topic:Inequality of real numbers with absolute signs d. Reflection
3.	Cycle III	a. Planning III (Results of reflection on Cycle II) b. Implementation of the Learning using *Cognitive Growth* model and Observation c. Topic: Domain and functions range d. Reflection

Table 4. Learning Activities in Cognitive Growth Model

Phase one Confrontation with stage-relevant tasks	**Phase two** Inquiry	**Phase three** Transfer
The students are faced with a. a puzzling situation that matches the stage of thinking development. b.	Getting the students' a. responses and asking for reasons Giving counter-suggestion, exploring the b. students' responses	Providing other related tasks related and exploring the students' reasons or arguments Giving counter-suggestion.

On the first stage, the students are given problems that are quite illogical on their minds or that are like puzzles. On this stage, the problem is presented relatively in accordance with the stages of the students' development. The choice of forms (verbal, nonverbal, or environmental manipulation) also depends on the stage of the students' thinking development. They choose the problem according to the provisions of the lecturer.

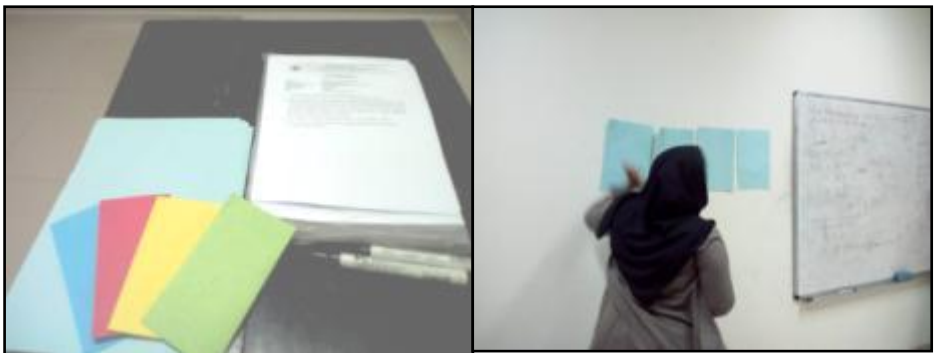

Figure 1. First Stage of Cognitive Growth Model

The second stage is used to look at the students' responses and investigate their level of reasoning. Generally, this stage consists of asking for reasons and giving counter-suggestions. The initial question depends on the types of the tasks, for example with "what do you think?" Or "what do you understand?" for the positive justice tasks, or "explain the steps you use to solve this problem"For the correspondence ones. Furthermore, they are asked to write the results of their works on the board.

Figure 2. Second Stage of Cognitive Growth

This second stage aims to get the right responses from the students. Each counter-suggestion aims to check their ability to defend their reasons.

The third stage aims to investigate whether the students will give the same reasons in different but related assignments. Once again, the lecturer presents the problem; the students deliver their views; the lecturer asks for a reason and then gives a counter-suggestion.

Figure 3. Third Stage of Cognitive Growth Model

The students' critical thinking skills obtained using the CTAC sheet that contains some aspects of critical thinking indicators in Differential Calculus course are presented in Table 5.

Table 5. Results of Critical Thinking Test Abilities

Assessed Aspect	Cycle I	Cycle II	Cycle III
Analyzing the arguments	30,00%	26,67%	33,33%
Evaluating the information	23,33%	20,00%	26,67%
Synthesizing the evidence	20,00%	13,33%	20,00%
Drawing the conclusions	16,67%	13,33%	16,67%
Average	22,50%	18,33%	24,17%

Based on the data in Table 5, after implementing the learning using cognitive growth model, there are 10 students who have reached the indicator of analyzing arguments. Among these 10 students, 8 students have been able to reach the indicator of evaluating information. Furthermore, there are 6 students who are able to synthesize evidence. However, only 5 students are able to draw conclusions and solve problems in accordance with available information and evidence. Thus, there are only 10 students having correct answers in the initial analysis, while the other 20 students have different answers. Most students are not careful in solving inequality in fractional forms. Some students have been able to show the completion steps, but they are not sure of the truth of their answers and are not careful in their arithmetic operations.

Furthermore, the researcher analyzes the results of the students' works to identify their critical thinking skills. Figure 4 shows the students' answers the problem of inequality of the real form of fractions by subject A.

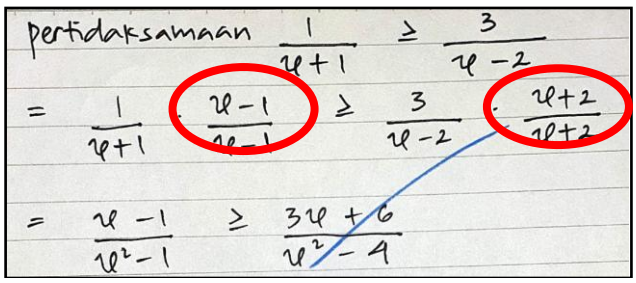

Figure 4. Answer of subject A

Figure 4 shows that there are mistakes made by subject A, namely errors in the calculation process and strategy. The students should replace $\frac{3}{x-2}$ into the left side, but they actually multiply each term with the opponent of the denominator. This causes the solution to be more complicated, so they cannot continue to solve it. Based on the analysis related to indicators of critical thinking, subject A has not been able to analyze the arguments of the question to get the right way to solve it. Below is an excerpt from the researcher interview with subject A related to problem solving in Figure 4.

P : On the question of inequality in fraction forms, how would you solve it?

A : Because each side is not yet the same, it should be multiplied by the opponent of the denominator.

P : Is it just the same with the concept of rationalizing?

A : Yeah I think so

P : Is not that for the root shape?
A : I am still confused to be honest… I just try to multiply it.
P : Have you found the answer?
A : Yes… but it's getting complicated...I think it is enough for me.

The results of the interview with subject A shows that he is not yet able to analyze the argument of the question. Besides, he has also been able to assess the definition of the problem by explaining the formulation in detail. Based on the triangulation of the test of subject A and the results of the interview, it can be said the indicator of analyzing the arguments is valid. Therefore, it can be concluded that subject A has not been able yet to achieve the initial indicator of critical thinking, which is analyzing the argument.

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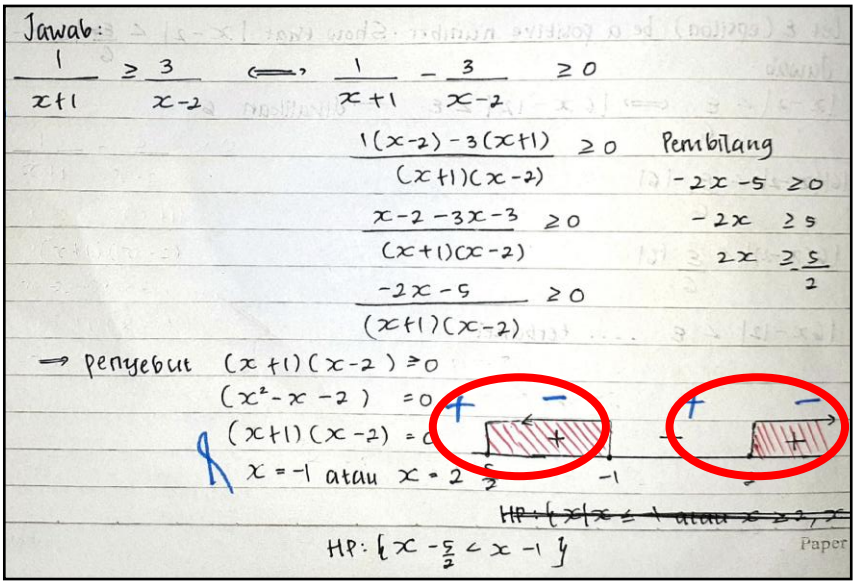

Figure 5. Example of the Answer on the Question of Inequality of the Real Numbers Fraction forms by Subject B

Based on the Figure 5, subject B made an error in checking the positive and negative regions of the number line. Subject B does not substitute a number not in the overall inequality form but only in the denominator. Based on the achievement of critical thinking indicators, subject B is able to analyze arguments and evaluate information. However, the indicators of synthesizing evidence or checking have not yet been accomplished.

During interviews, not all students can conclude whether all of the answers are correct. Only 5 students can conclude that all possible answers are correct. Others still aren't sure that all of the answers are correct.

Script 2. Excerpts of the researcher's interview with subject B regarding the indicator of synthesizing evidence on the problem of inequality of real numbers in fractions

P : Please re-check your answer. Have you been sure?
A : I have, Mam….
P : Please check the answer area and see it more carefully.
A : I think it's been correct.
P : Do it, once again

A : Ups sorry, I only change into the denominator. It should be from the initial equation.
P : Could you fix it?
A : Sure, I could
P : How is the result? Is it still the same?
A : No, it isn't… the answer is false...I am so careless

The interview excerpt shows that subject B is able to state the reasons or explanations for the test questions well without any hesitation with the answer given. Although at first it was wrong, he then corrected his own mistakes until it was discovered that he could fully do it. In addition, subject B is also able to provide the right reasons and be able to evaluate the information obtained on the indicators of critical thinking.

The results of the analysis of the achievement of indicators of critical thinking on the inequality question of real numbers with absolute signs show that there are about 9 students or 30% who have reached the indicator of analyzing arguments. However, 2 students fail to achieve the indicator of evaluating information. In synthesizing the evidence, only 6 students or 20% are able to achieve it. But, one student fails to draw the conclusions precisely. Therefore, only 5 students or 16.67% have been able to draw conclusions well.

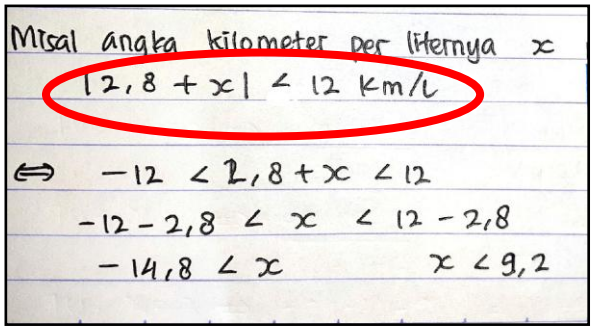

Figure 6. Example of Answer on Problem of Inequality of Real Numbers with Absolute Signs by Subject B

Based on the results of the written answers in Figure 6, an error is made by subject B, where he expresses his confusion about the mathematical model of the story problem. Ideas in making mathematical models of the questions asked are very diverse and mostly wrong. Some errors in concluding a problem are also very lacking on this problem. Therefore, non-routine questions like this must be accustomed to be given to the students. This is sought to improve their critical thinking skills.

The results of the analysis of the achievement of indicators of critical thinking on the domain and range of functions topics show there are 8 students or 26.67% who have been able to analyze the arguments and 13.33% have reached the indicator of evaluating information. However, there are only 4 students or 13.33% who have achieved the indicator of synthesizing the evidence conclusions. The same number also happens on the indicator of drawing conclusions.

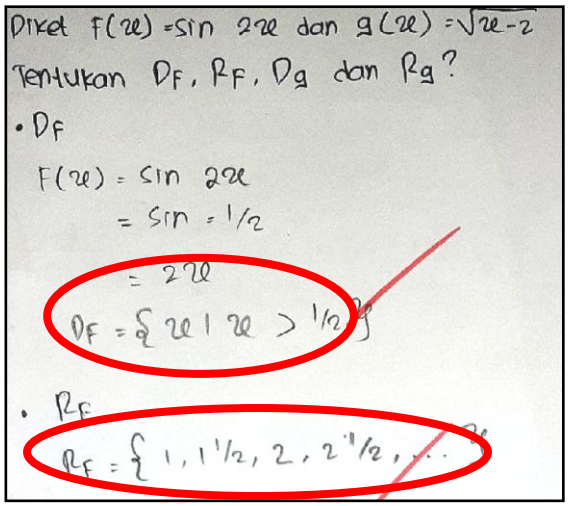

Figure 7. Example of The Answer on Domain and Range Function Problem

Based on the results of the answers written in Figure 7, the students tend to accept the information of a question without trying to evaluate it. They are also not careful about the information available. This shows that they are accustomed to solving routine problems and assume what is known must be in line with what is asked.

The results of the analysis of the average achievement of critical thinking indicators in all cycles are presented in a bar diagram in the following Figure 8.

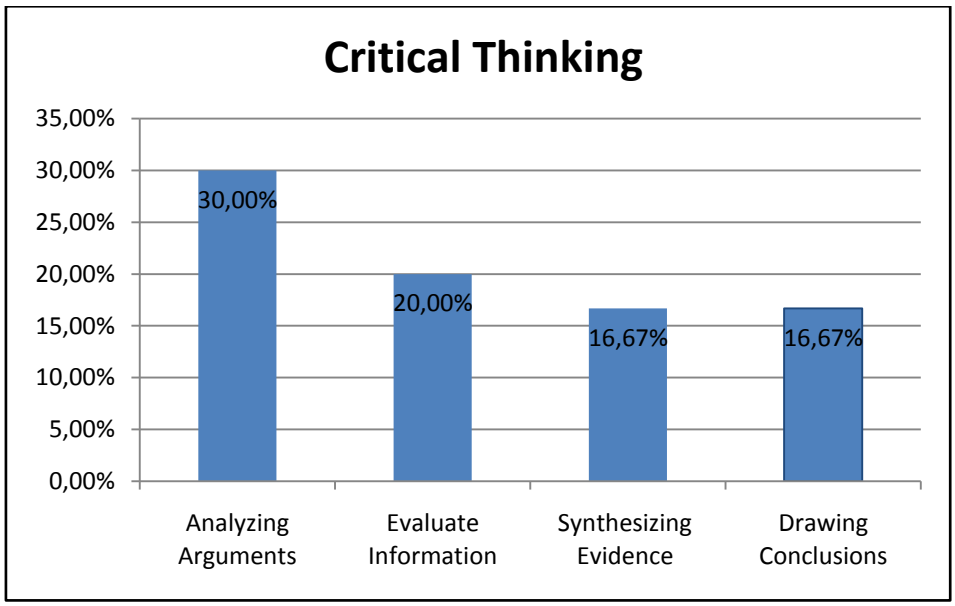

Figure 8. Bar Chart of Average Achievement of Critical Thinking Indicators

Based on Figure 8, there are only 30% students who have reached the indicator of analyzing arguments in the three cycles. This means that the students' skills to think critically is still low, while those who are able to achieve the drawing conclusions indicator are only five. Therefore, we need a specific treatment or training to improve the critical thinking skills of the first semester students, especially in differential calculus course.

Based on the results of data analysis regarding the achievement of the indicators of critical thinking, it is indicated that the critical thinking of the first semester students as the fresh high school graduates is still weak. Aizikovitsh-Udi & Cheng (2015) asserted that critical thinking must be a pervasive basis of the educational experience of all levels,

ranging from pre-school to high school and university, and equipment and structured programs in critical thinking skills must begin by introducing the right character (disposition) and turn to the development of critical thinking skills. Furthermore, at the university level, the students must be equipped with sufficient critical thinking skills, and the lecturers should be able to prepare them for their future. This is in line with the opinion of Mason (Lunenburg, 2011) stating that the concept of critical thinking is one of the most significant trends in education and has a dynamic relationship in how the lecturers teach and howthe students learn.

Sometimes, the students are not accustomed to face the problem-solving questions, while the problem-solving process is one of the demands of critical thinking assessment (Thompson, 2011). Furthermore Ben-chaim, Ron, & Zoller (2000) explained that the skills to think critically is very important to be successful in life, as a step for change to keep moving forward and as complexity and mutual dependence increase. The students tend to trust and accept raw information from the problems given without evaluate them first. Therefore, only few students are able to analyze information and synthesize the evidence provided in the problems. Trust in information given questions will affect their decisions making process. When the information provided is incomplete, it will rise different perceptions, and it can lead the students to draw inaccurate conclusions.

Conclusion

Based on the results of the research and discussion, it can be concluded that the mathematical critical thinking skills of the students in solving problems on differential calculus topic compiled based on the indicators of mathematical critical thinking skills in learning using cognitive growth model has been improved well. This is adjusted to the achievement of critical thinking indicators which include analyzing arguments, evaluating information, synthesizing evidence, and drawing conclusions. In the first cycle, the indicators achievement is mostly dominant in the aspect of analyzing the argument. However, in the second cycle, there is a decrease in the achievement of the indicators of critical thinking in all aspects. This becomes a reflection in cycle three for improvement. In the cycle three, there is an increase in the achievement of the indicatorsof analyzing the argument and reaching the aspect of evaluating information. Likewise, the improvement can also be seenin the aspect of synthesizing evidence, even they are able to reach the indicator of drawing conclusions optimally.

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