The Level of Meta-global Algebraic Critical Thinking Ability of Mathematics Education Students

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Submission date: 31-Jan-2021 09:24AM (UTC+0700)

Submission ID: 1497925620

File name: 10. The Level of Meta-global Algebraic Critical Thinking Ability of Mathematics Education Students.pdf (414K)

Word count: 4536

Character count: 26683

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Abstract— The aim of this study was to find out the description of the level of students critical thinking ability in solving valid and reliable meta-global algebraabic questions. The method used was explorative qualitative descriptive method. The data were collected through written test and interviews. The subjects of this study were the 1st year students of Mathematics education study program of Universitas Negeri Semarang. In brief, this study resulted valid and reliable Level of Meta-global Algebraic Critical Thinking Ability (LMACTA) as follows: LMACTA 4 (very critical), LMACTA 3 (critical), LMACTA 2 (quite critical), LMACTA 1 (less critical), and LMACTA 0 (uncritical).

Index Terms— Levelling, Critical Thinking, Meta-Global Algebra.

1 Introduction

The purpose of mathematics education is not only to serve subject matter, but also to prepare students to face the social demands of society. One of which is the ability to think at a higher level. Heong et al. (2011) argues that high thinking ability is an important aspect in the teaching and learning process, especially in higher education institutions. Conklin (2012: 14) confirms the characteristics of high thinking ability include critical and creative thinking. Again, Thomas (2011) states that critical thinking should be developed in the university from the first year, as a result students can overcome their future problems as well be beneficial for the company they work in later on. Based on the preliminary study, critical thinking is a highly important part in mathematic learning. For more, it is necessary to develop and train the ability of the 1st year students in critical thinking.

In fact, many experts have examined critical thinking including Ennis (1996, 2011), Paul & Elder (2008), Perkins & Murphy (2006), Jacob & Sam (2008), Facione (2013), and Watson & Glaser (2008). According to Ennis (1996) the elements in critical thinking are focus, reasoning, conclusion, situation, clarity, and comprehension. Watson & Glaser (2008) distinguish critical thinking competencies in 5 aspects, namely inference, assumptions, deduction, interpretation, conclusions and evaluation. Meanwhile, Facione (2013: 5) states that there are six aspects of critical thinking abilities, covering interpretation, analysis, conclusions, evaluations, explanations, and self-regulation. Perkins & Murphy (2006) have also examined critical thinking and produced 4 stages of critical thinking namely clarification, assessment, inference, and strategy. In addition, Jacob & Sam (2008) formulate the stages of critical thinking, including clarification, assessment, inference, and strategy. Based on the similiraty of indicators and stages mentioned above, this study took several stages of critical thinking, namely (1) Interpreting Information, (2) arguments analysis, (3) conclusions drawing, and (4) arguments evaluation.

Moreover, experts have formulated critical thinking levels, such as Paul & Elder (2008), Greenlaw & DeLoach (2003), and Rasiman (2015). Regarding experts' opinions, the level of critical thinking ability of each person is different from low into high level. Indeed, an assessment for critical thinking ability requires several criteria. These criteria can be used as a guide to determine the quality of students' ability in critical thinking and their development during the mathematics learning process.Besides critical thinking ability, algebraic thinking is also an interesting field to study. Many experts have defined Algebra, including Berdnaz, Kieran & Lee (in Ulusoy 2013), Driscoll (1999), Vance (1998), Blanton and Kaput (2011), and Panasuk (2010). From these experts' opinions, it can be concluded that algebra is a part of mathematics that deals with expressions which is manifested in the form of symbols or variables for problem solving, analyzing functional relations, and determining the structure of the system image. Several studies have already examined algebraic thinking, as follows Knuth et al (2005) examines the understanding of variables and equals sign. Panasuk (2010) examines the functional relations between variables and symbol manipulation in algebraic forms and equations. Blanton and Kaput (2011) reveal the functional relationships between variables and arithmetic calculations. Vance (1998) and Driscoll (1999) examine the representation of quantitative situations involving variables. Kieran (2004) classifies algebraic thinking in 3 algebraic abilities namely generational, transformational, and meta-global abilities. However, those research observations are still rarely focused on critical thinking in the field of algebra. There were several studies related focusing on meta-global algebraic thinking ability, including Nobre et al. (2011), Eisenmann & Even (2011), Tabach et al. (2013), Tam & Thang (2014). Most of them only saw how students used other activities such as generational and transformational thinking activities in solving meta-global problems yet they rarely observed how students think critically in solving problems of meta-global algebra. Therefore, critical thinking in meta-global algebra becomes an interesting study in mathematics education field. Indeed, this study focused on the ability of meta-global algebra. According to Agoestanto (2019), the ability of meta-global algebra is influenced by generational and transformational abilities, so meta-global ability describes generational and transformational abilities. The meta-global algebra ability is the ability to use algebra as a problem solving tool, mathematical problems modeling, an ability related to the

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nature of algebraic structure, generalization of an operation, mathematical analysis, and mathematical proof tools (Kieran, 2004). Based on ciritical thinking stages, and meta-global algebra, the followings meta-global algebra stages are designed: (1) interpreting information into modeling forms on algebraic problems related to other fields of study and proof, (2) analyzing arguments on algebraic problems related to algebra with other fields of study and proof, (3) drawing conclusions on algebra problems related to other fields of study and proof, (4) evaluating arguments on algebra problems related to other fields of study and proof of problems. In particular, interpreting information includes (a) identifying information on algebraic issues related to other fields of science and proof, (b) identifying existing problems or things that will be proven, (c) defining the problem in more detail by modeling algebraic forms. At the stage of analyzing the argument includes activities (a) connecting information in the question to determine the problem solving / proof strategy and (b) carrying out the question / proof solving procedure in accordance with the chosen strategy. At the stage of drawing conclusions includes the activities of (a) drawing conclusions according to facts and (b) making conclusions that are appropriate to the problem. Furthermore, the argument evaluation phase includes the activities of giving reasons for each problem solving / proof procedure. However, in this study, algebraic problems related to other study field are limited only to mathematics study. Based on the description above, the purpose in this study was to describe the level of critical thinking ability of meta-global algebra that is valid and reliable.

2 METHOD

This study used qualitative approach, and descriptive exploratory design. It was started by data mining in form of views from informants regarding detailed or original story based on their point of views. Meanwhile, things described in this study was the meta-global algebra critical thinking ability. To describe this ability, the researchers performed a direct observation by analyzing students' work in algebra, and interviews. The interviews were aimed at revealing the overview of students' critical thinking ability.

2.1 Subject

The research subjects were the first year students Mathematics Education Study Program of Mathematics department at Universitas Negeri Semarang who took the Introduction to Basic Mathematics course in 2018/2019. They were chosen because (1) the students were already in the level of formal thinking so they were able to think abstractly to produce critical answers, (2) the students have studied school algebra so that they had knowledge and experienced in meta-global algebra materials, (3) first years is a transition year from school to higher education level so that the results of the exploration of critical thinking of meta-global algebra could be used as a guide in learning algebra in the school and first year of college.

2.2 Data Collection and Data Analysis

The data collected in this study were in the forms of facts about the ability to think critically about meta-global algebra. These data were collected using written tests and deep interviews based on meta-global algebra written tests. They included: (1) data reduction; (2) data presentation / categorization; and (3) drawing conclusions / verification.

2.3 Validity and Reliability

To empirically validate the hypothetical theory of KBKAM levels, the researchers performed data collection. It was carried out after finding students who met the criteria of the research subject. The data collection process began with the way study worked on the written test. Then the test results of the i-th subject (i = 1, 2, 3, ..., 21) were analyzed. If there found hesitation about the written answer of the i subject, the i subject was interviewed for the purpose of clarifying the written test work. From the results of this analysis the researchers obtained the i-th subject data in writing. After a few days the i-th subject was given a KBKAM problem solving test, and interviewed about the procedures and results of the KBKAM problem solving given. From the results of this analysis the researchers obtained the i-th subject data verbally. The triangulation method was then performe by comparing the i-th subject data in the written test, and the i-th subject interview results. The data which have been triangulated were considered valid. Meanwhile, those who were found different were reduced, and categorized as other findings of this study.The valid i-th subject data was compared with the proposed KBKAM level characteristics to find out the characteristics of the i-th KBKAM level characteristics. The characteristics of the i-th subject were empirically valid if they met the proposed KBKAM level. In this way, the level of the proposed KBKAM can be said as in accordance with the reality in the field, or in other words the level of the proposed KBKAM is supported by the data in field. To find out whether the proposed level of KBKAM thinking met the reliability criteria or reliable, the researchers performed comparison analysis of the i-th subject and j-th subject.

3 RESULTS AND DISCUSSION

The meta-global algebra critical thinking was tested by giving students a test of the critical thinking skills of the Meta-global Algebra. During the test, the field recording process was carried. It obtained from the results of student work, videos, and field notes. These data were analyzed based on the critical thinking skills needed. Based on the analysis, the results were classified into levels covering very critical, critical, quite critical, less critical, and uncritical. After that, the students were interviewed using a guidance to check meta-global algebra critical thinking. The interview resulted video recording and field notes. These data were transcribed and analyzed to gain the description of the desired critical thinking ability.

TABLE 1
THE COMPARISON OF THE CHARACTERISTICS OF KBKAM S4-A, S4-B, AND S4-C

No	Indicator/ stage	Subject S4-A	Subject S4-B	Subject S4-C
		Information	Information	Information
1	Interpreting Information	Satisfactory	Satisfactory	Satisfactory
2	Arguments Analysis	Satisfactory	Satisfactory	Satisfactory
3	Conclusion Drawing	Satisfactory	Satisfactory	Satisfactory
4	Arguments Evaluation	Satisfactory	Satisfactory	Satisfactory

The results of the meta-global algebraic critical thinking skills of each indicator / stage are presented as follows:
Based on table 1 we can conclude that students who were

very critical in meta-global algebra (S4) were able to interpret information, perform algebraic forms modelling, analyze arguments, draw conclusions, and evaluate arguments of algebraic problems related to other fields of mathematics and proof.

TABLE 2
THE COMPARISON OF THE CHARACTERISTICS OF KBKAM S3-A, S3-B, AND S3-C

No	Indicator/ stage	Subject S3-A Information	Subject S3-B Information	Subject S3-C Information
1	Interpreting Information	Satisfactory	Satisfactory	Satisfactory
2	Arguments Analysis	Satisfactory	Satisfactory	Satisfactory
3	Conclusion Drawing	Satisfactory	Satisfactory	Satisfactory
4	Arguments Evaluation	Unsatisfactory	Unsatisfactory	Unsatisfactory

Based on table 2 we can conclude that the students who were critical of meta-global algebra (S3) were able to interpret information, perform algebraic modeling, analyze arguments, and draw conclusions, but were unable to evaluate arguments for algebraic problems related to other fields of mathematics and proofing problems.

TABLE 3
THE COMPARISON OF THE CHARACTERISTICS OF KBKAM S2-A, S2-B, AND S2-C

No	Indicator/ stage	Subject S2-A Information	Subject S2-B Information	Subject S2-C Information
1	Interpreting Information	Satisfactory (other fields of mathematics and proof)	Satisfactory (other fields of mathematics and proof)	Satisfactory (other fields of mathematics only)
2	Arguments Analysis	Satisfactory (other fields of mathematics only)	Satisfactory (other fields of mathematics only)	Satisfactory (other fields of mathematics only)
3	Conclusion Drawing	Satisfactory (other fields of mathematics only)	Satisfactory (other fields of mathematics only)	Satisfactory (other fields of mathematics only)
4	Arguments Evaluation	Satisfactory (other fields of mathematics only)	Satisfactory (other fields of mathematics only)	Satisfactory (other fields of mathematics only)

Based on table 3 we can conclude that students who were quite critical of meta-global algebra (S2) were capable of interpreting information, modeling algebraic forms, analyzing arguments, and drawing conclusions well, but unable to evaluate arguments of algebraic problems related to other fields of mathematics or proof problem only.

Based on table 4, we can conclude that students who were less critical of meta-global algebra (S1) were able to interpret information, perform algebraic modelling in problems related to other fields of mathematics , but unable to analyse arguments, draw conclusions, and evaluate arguments about algebraic problems related to the Other Fields of Mathematics and proof.

TABLE 4
THE COMPARISON OF THE CHARACTERISTICS OF KBKAM S1-A, S1-B, AND S1-C

No	Indicator/ stage	Subject S1-A Information	Subject S1-B Information	Subject S1-C Information
1	Interpreting Information	Satisfactory (other fields of mathematics only and proof)	Satisfactory (other fields of mathematics only)	Satisfactory (other fields of mathematics only and proof)
2	Arguments Analysis	Unsatisfactory	Unsatisfactory	Unsatisfactory
3	Conclusion Drawing	Unsatisfactory	Unsatisfactory	Unsatisfactory
4	Arguments Evaluation	Unsatisfactory	Unsatisfactory	Unsatisfactory

TABLE 5
THE COMPARISON OF THE CHARACTERISTICS OF KBKAM S0-A, S0-B, AND S0-C

No	Indicator/ stage	Subject S1-A Information	Subject S1-B Information	Subject S1-C Information
1	Interpreting Information	Unsatisfactory	Unsatisfactory	Satisfactory (other fields of mathematics only)
2	Arguments Analysis	Unsatisfactory	Unsatisfactory	Satisfactory (other fields of mathematics only)
3	Conclusion Drawing	Unsatisfactory	Unsatisfactory	Unsatisfactory
4	Arguments Evaluation	Unsatisfactory	Unsatisfactory	Unsatisfactory

Based on table 5 we can conclude that students who were uncritical of meta-global algebra (S0) were unable to interpret information, perform algebraic modelling, analyze arguments, draw conclusions, and evaluate arguments about algebraic problems related to the other fields of mathematics and proofing.

4 DISCUSSION

Based on the analysis it was found that the subjects at a very critical level of meta-global algebra were able at all stages of critical thinking of meta-global algebra, covering: (1) Interpreting Information, (2) arguments analysis, (3) conclusions drawing, and (4) arguments evaluation. This is in line with Facione's (2013) research which shows that students at the highest level of critical thinking skills consistently do all or almost everything including: (1) interpreting evidence, statements, graphs, questions, etc., (2) identifying arguments salient (reasons and claims) pros and cons, (3) analyzing and evaluating various main alternative viewpoints, (4) drawing conclusions that are justifiable, wise, and correct, (5) justifying the main results and procedures, explaining assumptions and reasoning, and (6) thinking fairly following where the evidence and reason lead. Subjects at very critical, critical, quite critical, and less critical levels were able to work on the problem at the stage of information interpretation. They could work on the questions for the stage of information interpretation because they were accustomed to work on questions in which there are instructions about that stage, where the intended instruction is to gather information contained in the questions. This habit

occurred because students were often trained since they were at the middle school level, so they found it easy, especially for problems and proof related to metag-lobal algebra. This is in accordance with Thorndike's theory of the law of training (law of excercise) according to Sugihartono as quoted by Ainia et al. (2012) that the more often a behavior is trained, the stronger and more accustomed it becomes. In line with this fact, Larasati & Prihatnani (2018) state that a work that is done repeatedly will make the initially difficult works be easier to do. These habits made students able to work on the questions at the stage of interpreting information. This is in accordance with Ramirez et al (2016) which state that the ability to process information obtained from working memory in the brain can be sharpened by training. Accordingly, subjects at the uncritical level of meta-global algebra were incapable of information interpretation because they lacked of understanding in using variables, for example algebraic forms and were unable to model problems in algebraic form. Subjects at the very critical and critical level of meta-global algebra were able at the stage of arguments analysis, and conclusions drawing. It proved that the subject at a very critical and critical level of meta-global algebra were critical thinkers and able to analyze arguments. This is in line with Sumaryati (2013) who argues that the skill of analyzing arguments is one of the skills that must be possessed by critical thinkers. In addition, the ability to analyze is influenced by the ability of students to model problems in the form of algebra. Arseven (2015) explains that modeling problems into algebraic forms supports students in obtaining a mathematical framework in the analysis process. Therefore, research subjects who cannot model the problem well at the stage of interpreting information will have difficulty at the analysis stage. Subjects at the very critical and critical levels of meta-global algebra were able to draw conclusions because they were used to write conclusions on the final results of work. It made students who were able to analyze arguments correctly tended to be able to draw conclusions correctly. This is in line with the opinion of Sukmawati et al. (2013) that a process of forming attitudes that is carried out consistently through repeated experiences to the stage of independence will turn into habituation. Habit that is done repeatedly in working on the problem makes students able to draw conclusions if they are also able to analyze the arguments stage. Meanwhile, the subjects at a quite critical level were able to perform at the stage of analyzing arguments, and make good conclusions only for algebraic problems related to other fields of mathematics or proof. Based on the results above, the stage of arguments evaluation could only be done by the subjects at the very critical level of meta-global algebra. The ability to evaluate is a very difficult ability. Crompton et al (2019) research results show that the evaluation ability of the lowest students are comparable to the abilities to remember, understand, apply, analyze, and create. Whereas, for the stage of information interpretation, the subjects at the very critical, critical, quite critical, and less critical levels of meta-global algebra were able to do it. This is in line with Perkins & Murphy's (2006) research which shows that groups as a whole tend to be more involved in clarification and less in strategy than in the other three processes. Yet according to Perkins & Murphy (2006), strategies are realized by describing, proposing, or evaluating possible outcomes or actions. At the clarification stage based on Perkins & Murphy (2006) and at the stage of information interpretation in this study, both of them contained the same basic indicators of identifying information, identifying problems, and defining problems. It is clear that the group as a whole tends to be more capable at the stage of information interpretation than the stage of arguments evaluation.

5 Conclusion

The results of the study of Meta-global S4, S3, S2, S1, and S0 Critical Thinking Ability Levels obtained the following reliable results. (1) students are very critical of meta-global algebra (S4), students are able to interpret information, model algebraic forms, analyze arguments, draw conclusions, and evaluate arguments on algebraic problems related to other fields of mathematics and proofs, (2) students who are critical of meta-global algebra (S3) are able to interpret information, modeling algebraic forms, analyzing arguments, and drawing conclusions well, but are unable to evaluate arguments on algebraic problems related to other fields of mathematics and proofs, (3) students at the quite critical level of meta-global algebra (S2) are able to interpret information, model algebraic forms, analyze arguments, and draw conclusions, but are unable to evaluate arguments on algebraic problems relating to Other Fields of Mathematics or just a matter of proof, (4) students who are less critical of meta-global algebra (S1) are able to interpret information, model algebraic forms, but are unable to analyze arguments, unable to draw conclusions, and are unable to evaluate arguments on algebraic problems related to other fields of mathematics and proofs, (5) students who are uncritical of meta-global algebra (S0) are unable to interpret information, model algebraic forms, analyze arguments, draw conclusions, and to evaluate arguments on algebraic problems related to Other fields of Mathematics and proofing issue.

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