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Development of Mathematical Problems for Measuring Capabilities Critical Thinking and Problem Solving

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Abstract. Learning mathematics is expected to provide 21st century skills students need, that creativity and innovation, critical thinking and problem solving, communication and collaboration. This study develops mathematical problems in algebra content to measure the ability of critical thinking and problem solving. The method used in this research is the development research. The study consisted of two stages: preliminary and formative stages of evaluation that includes self-evaluation, expert reviews and one-to-one, small group and field test. Data collection techniques used walk-throughs, document, test, and interview. After going through the one-to-one and small group, the mathematical problems tested at the stage of field tests at class VIII B of SMP Muhammadiyah 1 Kartasura. The results of a test showed an average score of 72. This shows the ability of critical thinking and problem solving are good categories. The mathematical problems that have developed have potential effects on students' skills in critical thinking and problem solving. Thus, integrating mathematics problem solving and critical thinking into the curriculum is needed.

Keywords: *critical thinking, problem solving, math problems*.

1. INTRODUCTION

One of the strategic issues in the early decades of this century is the Asean Economic Community (AEC). Entering the era of AEC in 2015, Indonesian stakeholders would have to conform to international standards in order to survive in this global era. Similarly, the world of education, including mathematics education, to be able to excel in the international world. But unfortunately from time to time math skills in international forums not move right away either. This is evident from some of the results of a survey conducted by international institutions such as the Trends in International Mathematics and Science Study (TIMSS) and the Program for International Student Assessment (PISA), which ranks Indonesia that have not been encouraging among the countries surveyed.

TIMSS survey, conducted by The International Association for the Evaluation and Educational Achievement (IAE) domiciled in Amsterdam, take a focus on mathematics content and cognitive domain of students. Domain contents include Numbers, Algebra, Geometry, Data and Chance, while the cognitive domain covers the knowledge, application, and reasoning. The survey, conducted every four (4) years that he held from 1999 put Indonesia on position 34 out of 48 countries, 2003 at position 35 out of 46 countries, in 2007 at position 36 of the 49 states, in 2011 at position 36 of 40 countries, and in 2015 at position 45 of 50 countries as reported by Mullis et all [1].

Meanwhile, studies of three (3) yearly PISA, organized by the Organization for Economic Cooperation and Development (OECD), a UN agency based in Paris, aims to determine students' mathematical literacy. The focus of the PISA study is the student's ability to identify and understand and use the basics of mathematics required in everyday life. The study, conducted from 2000 ranks Indonesia as 39 of the 41 countries, 2003 at position 38 of the 40 countries, 2006 at position 50 out of 57 countries, in 2009 at position 61 out of 65 countries, in 2012 at position 64 out of 65 countries, and the last in 2015 at position 63 of the 70 countries as reported by OECD [2].

TIMSS and PISA studies the essence lies in the strength of students' mathematical reasoning and the ability to apply them in everyday life. This shows the weakness of students in connecting mathematical concepts that are formal within the context of real-world problems. Noting the low ability of Indonesian students in the survey, the Government of Indonesia, in this case the Ministry of Education and Culture has actually been anticipated by some changes in the curriculum. In the period 2000 to the present there have been three types of curriculum applied, i.e the 2004 curriculum, 2006 curriculum, and curriculum in 2013 (which has been completed revised). Although the curriculum has been changed, this has not been able to raise the students' achievement in international forums. Temporary observation showed that although the curriculum has been changed, the function and role of the teacher in mathematics, particularly related to how to deliver course material and practice questions of mathematics has not changed much.

In the information era, as the students have to compete in a global society, they are required to have creativity, critical thinking skills, communication, and collaboration, better known by the acronym 'Four Cs' [3]. Focus on providing the skills 4Cs, the learning of mathematics should elaborate on aspects of creativity and innovation, critical thinking and problem solving, communication and collaboration [4]. Aspects of creativity and innovation is intended that students can use various techniques to create new ideas that are useful, in detail, repair, analyze, and evaluate their ideas in order to develop and maximize the creative effort and demonstrate the authenticity of the findings, either individually or in groups. Aspects of critical thinking and problem solving means that students can reason effectively. They think systemically, to understand that the parts interact with one another. They make choices, decisions, and solve problems, both conventional and innovative. Aspects of communication and collaboration is intended that students know how to articulate thoughts and ideas effectively through oral communication, written, or nonverbal communication.

The ability of critical thinking and problem solving, which is one of the characteristics of high order thinking skills (HOTS), it seems not many implemented in mathematics learning in school. This is apparent from problems on the national exam of mathematics that requires only taking successive proportion HOTS 7.5%, 12.5%, and 10% by 2013 – 2015 [5]. Therefore, the learning of mathematics in schools should be developed so that it can elaborate on ability of critical thinking and problem solving. One effort that can be done is to provide the mathematical problems that require the HOTS in resolving a problem.

This paper describes the development of mathematical problems to measure critical thinking skills and problem solving. Brookhart [6] suggest that to measure high order thinking skills, the problems should be use novel material or in new context. The ability of students is measured in ability to identify problems, create mathematical models, choose a variety of problem-solving strategies, solve problems with mathematical models, and summed up the results. The idea of the development of matter refers to the PISA Framework in Indonesia setting.

2. RESEARCH METHOD

The research includes the development of research. Procedure to develop questions used through the preliminary stages and formative evaluation stage that include self-evaluation, expert reviews, one-to-one, small group, and a field test. Objects that are developed are mathematical problems PISA's like content change and relationships that it refers to the topic of algebra. This topic selected because algebra is foundation for mathematical modelling. The research subjects taken are VIIIB grade students at SMP Muhammadiyah 1 Kartasura. The research subjects were included in stages one-to-one, small group and field test to measure the ability of critical thinking and problem solving. Each item will be given a score based on indicators and criteria to measure critical thinking skills and problem solving. Indicators and criteria that are used as shown in Table 1. Thus, the maximum score for each question is 6. The indicators adapted from [7].

Table 1. Indicators and criteria for critical thinking and problem-solving

No	Indicator	Criteria	Score
1.	Analyze the problem	Students are able to identify the problem by writing what is known and what is being asked by the context	1
2.	Make formulations	Students are able to create a mathematical model of the results of the identification problem.	1
3.	Integration and synthesis	Students are able to connect the various elements of knowledge, related representations, and procedures to solve the problem.	1
4.	Using structural/ formal framework	Students are able to write down steps to resolve correctly and mathematically correct answer.	2
5.	Summing up the result	Students are able to make valid conclusions on the basis of information and evidence to answer the problem in context..	1

3. RESULT AND DISCUSSION

Research has designed 5 (five) themes containing 15 math problems similar PISA in change and relationships content. Questions designed cover a solo great sale, party table, a bicycle for disabilities, examinations, and religious activities. Questions designed are validated by using triangulation techniques. Furthermore, the draft revised is based on the validator's suggestion and test results of one-to-one.

At the stage of a small group, test using questions were developed in general can be done well. This stage consists of two low-qualified students, two students capable of being, and two-capable smart. Students were asked to read, understand and work on the problems. After working on the problems, students are asked to complete a questionnaire about the shows what students do after working on the problems given by the researchers. At this stage, there is an increasing in students understanding of questions that have been revised at the stage of one-to-one. Noting the analysis of the results of the students' answers and comments of students at the stage of small group, students have been able to understand the questions given by the researchers.

Table 2. Distribution of scores of critical thinking skills and problem-solving

Interval	Frequency	Percentage (%)	Remark
76 – 90	10	36.20	Very good
56 – 75	11	42.60	Good
41 – 55	4	21.20	Fair
0 – 40	0	0	Failed
Total	25	100	

Phase field test is needed to see the potential effects math problems on the ability of critical thinking and problem solving. The maximum score that can be obtained by students is 90 out of 15 questions. Of the 25 student participants in field test, it is obtained an average score is 72. The distribution of scores of critical thinking skills and problem solving can be seen in Table 2. These results indicate that about 78.8% of the students have good ability. These results indicate an increase in the mean when compared to pretest results as shown in Table 3. The average score for pretest is 56. Result of pretest indicate that about 36% of the students have good ability. This shows that based on the criteria, the problems have been developed have potential effects for measuring critical thinking skills and problem solving.

Table 3. Distribution of scores of critical thinking skills and problem-solving before and after field test

Interval	Pretest Frequency	Pretest Percentage (%)	Posttest Frequency	Posttest percentage
76 – 90	2	8.0	10	36.20
56 – 75	7	28.0	11	42.60
41 – 55	14	56.0	4	21.20
0 – 40	2	8.0	0	0
Total	25	100	25	100

Development of mathematical problems have resulted in a set of problems that can be considered valid and practical. Be valid illustrated by the results of the validator assessment, where the validator declares both based on content, context, and competencies. Content is similar PISA with the content change and relationships. Context consisting of the context of work, private, public, and scientific (science). Meanwhile, competencies which include competencies of reproduction, connections and reflection. Indicators used are also show the students' ability to identify problems, create mathematical models, determine the mathematical way that is relevant to the problem, provide an explanation using the model, make the relationship between the statements, as well as in evaluate the results as a matter of context. Moreover, the language used in question does not contain a double interpretation, and it is easily understood by students.

Akker, et al [8] found that the quality of the instrument are three criteria of validity, practicality, and has a potentially effect. Meanwhile, Anisah et al [9] explain that validity can be from experts, peers and teachers of mathematics, practicality means that its use is easy and can be used in the learning process, and the matter has a potential effect can be seen from the test results critical thinking skills and problem solving. Problems considered valid and practical are drawn from the test results of one-to-one to small group, where all students are able to use the questions well. The analysis of test results showed that the problems can be used to train critical thinking skills and problem solving of the students. From table 2 it can be seen that there are 10 students (36.2%) who had the very good category, there are 11 students (42.6%) who have a good ability.

In general, the results of the test in one meeting note that the students' skills in critical thinking and problem solving are mostly good. Students were categorized as having the ability of mathematical reasoning that both have been able to identify the statement and determine the mathematical way in solving the problem, provide an explanation by identifying statements and determining the mathematical way that is relevant to the problem, give an explanation to the model, make a pattern relationship between the statement and made a statement support or refute the argument [10].

Some students who work on the problems of the researchers, are still not able to achieve cognitive ability in the competence of reflection as well as on the first theme (solo great sale), the second theme (counter party), the theme of the third (bicycle with disabilities), and the theme of the fifth (activity religious). In a matter related to the competence of reflection, there are only a few students being able to do it. Sylva, Zulkardi, and Darmawijoyo [11] state that the students' abilities in reading and interpreting the meaning of matter into a mathematical problem on average is good enough, but it takes a long time less capable students to understand. Students who are belong to the category of the less capable of reasoning have difficulty in reading and understanding the meaning of matter, so that it can be seen that mathematical literacy of students are still low.

Difficulties in identifying problems make students' difficulties in determining the mathematical way to solve the problems in question. The difficulties experienced by students generally cover (1) difficulty connecting with the real situation of mathematics, (2) difficulty in determining the relationship of each element / information known on the matter, (3) the difficulties in calculating and less scrupulous. These difficulties resulted in student’s failure in solving problems.

These results are in accordance with Edo, et al [12] who found that generally students experience difficulties in the process: (1) formulating the problem in everyday life into mathematical models, such as interpret the context of real situations into mathematical models, understand the mathematical structure (including regularity, relationships, and patterns) in the matter, (2) evaluating the reasonableness of the mathematical solution in the context of real-world problems. This is because students are less practiced in doing math problems that require mathematical reasoning ability. The students are also exerts less a matter of implementing the learning materials at the school to the real situation. This situation implies that critical thinking skills are poorly trained.

From the analysis of test results document that uses mathematical problems of stage one-to-one to the stage of field tests, mathematical problems are made to hone critical thinking skills and problem solving. Students begin to identify the problem in question, relating to the appropriate mathematical situations to solve the problems in question. According to the results of interview with the students, the problems developed can lead students to explore mathematical ability to provide answers to questions along with explanations, steps to resolve, and the conclusions of the answers obtained. It also suggests that the questions developed have potential effects on students' mathematical ability [13].

In this research, the majority of students are able to solve problems and those included in the category of competence is good, but in reality in a study conducted by researchers showed that most students of class VIII B have the ability to think critically and problem-solving well. It can be used by the actors to develop of education in secondary education, especially in critical thinking and problem solving. Moreover, Ahyan et al [14] explained that by familiarizing students working on the problems of PISA type will enhance high-level thinking skills of students. This development is an effort to equip students with skills needed in the context of Asean economic community face today.

Aware of the importance of critical thinking skills, efforts to improve the ability of students in critical thinking and problem solving are also carried out in many countries. Salih [15] shows that through analogical tasks, creative and critical thinking skills as well as their thinking strategies developed significantly. Meanwhile, Ju-Yeen et al [16] enrich the authentic blended learning environment to enhance problem-solving skills. In line with the advancement of information and communication technology, Jacob and Sam [17] have been using online discussion forums to gauge the ability of critical thinking and problem solving. Moreover, Rasiman [18] recommend leveling critical thinking to be used on mathematics education. Integrating mathematics problem solving and critical thinking into the curriculum need to be done since primary education [19].

4. CONCLUSION

This research has passed the prototype stage consisting of expert reviews, one-to-one, small group, and field test. Studies have produced mathematical problems in algebra topics are valid and practical. Validity of the problems based on the validator assessment where states are either based on content, context (work, public, scientific, and personal), competence (reproduction, connections, and reflection), and language.

Based on the results of field tests using questions that have been developed, the students gain an average score of 72. This means that the ability of critical thinking and problem solving is good. Thus the mathematical problems that have been developed can be said to have a potential effect on the ability of critical thinking and problem solving. Nonetheless, there are still some students who have sufficient mathematical reasoning abilities. Therefore, the efforts to elaborate mathematics learning to provide critical thinking skills and problem solving needs to be improved.

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