

# Development of Learning Materials Oriented on Problem-Based Learning Model to Improve Students' Mathematical Problem Solving Ability and Metacognition Ability

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## ABSTRACT

This study aims to analyze the effectiveness of learning materials oriented on problem-based learning models, the improvement mathematical problem solving ability and students' metacognition ability. Learning materials that developed are lesson plan, student book, student worksheet, mathematical problem solving ability and students' metacognition ability test. This research is a development research by using the development model of Thiagarajan, Semmel and Semmel (1974). Valid learning materials according to experts, tested in class VII of SMP Negeri 13 Medan (seventh year junior high school). The results showed that learning materials oriented on problem-based learning met the effective criteria and improved mathematical problem solving and metacognition ability. Level students' metacognition when problem solving met level of strategic use, aware use, and tacit use.

**Keywords:** development of learning materials, mathematical problem solving ability, metacognition ability, problem-based learning

## INTRODUCTION

Education is an important field in determining the quality of a nation. In formal education, mathematics is one of the fields studied by students. Students are expected to use mathematics and mathematical thought patterns in everyday life, and learn various types of science that emphasize logical rules and also the ability to apply mathematics (Saragih & Napitupulu, 2015). In other words, students are expected to be able to achieve the High Order Thinking Ability or Higher Order Thinking Ability (HOTS). Problem solving is the main thing in learning mathematics. Liljedahl et al. (2016) said that mathematical problem solving has long been seen as an important aspect of mathematics, teaching mathematics, and learning mathematics. Problem solving ability involves high and low-level thinking (Hoiriyah et al., 2014). With problem solving ability, students can improve their thinking ability, apply procedures, and deepen conceptual understanding (Ranjan & Gunendra, 2013).

In addition to problem solving ability, metacognition ability is also related to learning and thinking and problems solving competencies. Aljaberi and Geith (2015) said that metacognition ability defined as competencies are interrelated to learning and thinking, and consist of many abilities that needed for effective learning, critical thinking, reflective assessment, problem solving, and decision making. Kazemi et al. (2010) said that problem solving ability are recognized as complex interactions between cognition and metacognition. The same thing was also stated by Sengul and Katranci (2012) that individuals can be more successful in

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problems solving by having metacognition experiences. Therefore, metacognition has a close relationship with problem solving in learning, which in solving problems is needed metacognition process.

### **Mathematical Problems and Mathematical Problem Solving Ability**

Problems in mathematics are interpreted as a situation where a person cannot answer questions/test in a way or habit that applies. Problems in mathematics are questions that is solution without using routine methods or algorithms (Ruseffendi, 1991). Problems are cases that arouse the desire of individuals to solve them or finish them (Aydogdu, 2014). Problems in mathematics are present in non-routine problems or word problems that cannot be solved by using only a certain formula but to solve it, correct procedures and deeper thinking are needed.

Problems solving is not only the purpose of learning mathematics but also the main means of learning mathematics. Saragih and Habeahan (2014) said that problem solving is part of a standard mathematical process that is very important because in the learning and completion process students' allowed to use ability and experiences that they must apply in solving non-routine problems. To solve a problem, a problem solver can use the strategy or steps formulated by Polya (1973), that is, we must first understand the problem; we must see clearly what is, being asked. Second, we must see how things are connected, how the unknown is connected to data, to get ideas about solutions, to plan solutions. Third, we carry out the plan. Fourth, we pay attention to the solutions that have been obtained, we review them again and discuss them. Batubara et al. (2017) stated that problem solving ability are strategies or way's students solve problems using systematic actions. The success of problem solving is not possible without the first representation of the problem properly (Sajadi et al., 2013).

Students' mathematical problem solving ability can be defined as students' ability to understand problems, plan problem solving strategies, carry out selected strategies of resolution, and re-examine solving these problems to subsequently make solutions in a systematic and inseparable way with proper representation of the problem (Saragih & Habeahan, 2014; Polya, 1973; Batubara et al., 2017; Sajadi et al., 2013).

Although mathematics is a very important subject in formal education and is closely related to human life, mathematics is not a topic of interest the student's and many students face difficulties in mathematical problem solving due to inability to acquire many mathematical ability and lack cognitive learning ability (Simamora et al., 2017; Tambychik et al., 2010). Based on preliminary observations at SMP Negeri 13 Medan on 8<sup>th</sup> – 11<sup>st</sup> November 2017, the results of interviews with teachers stated that mathematics is a subject that is not in demand by most students. It was also found that many students did not like mathematics because mathematics was too difficult. Other facts also show that student's mathematical problem solving ability are still low. The low mathematical problem solving ability of students can be seen from the results of diagnostic tests in the form of story questions. The low mathematical problem solving ability is an important and urgent problem to be solved.

### **Metacognition Ability**

The term metacognition was used for the first time by Flavell in 1976. According to him, metacognition consists of knowledge, experience and rules that function as important elements and contribute to the success of problem solving. Metacognition is thinking about what is, thoughts. This is also supported by Smith (2013) who said that metacognitive is a person's personal ability to understand how he thinks, imagine that is in his mind, and controlling he learns based on the understanding and results of reflection of his thoughts.

Metacognition is also said to be one component of human cognition which helps in regulating processes and one's cognitive behavior and is very relevant for learning and includes the ability of students to understand cognitive processes (Gurbin, 2015; Ahghar, 2012). This is in line with Gul and Shehzad (2012); Jaafar and Job (2010) state that metacognition knowledge is related to knowledge about cognition such as knowledge of ability and strategies that are good for the student's working to improve learning and have great potential in increasing student's learning significance in the classroom. NCREL (2007) presents three basic elements of metacognition specifically in the face of tasks namely: (a) developing an action plan, (b) regulating or monitoring actions and (c) evaluating actions.

The students' metacognitive ability referred to in this study are the process student's awareness of their own cognitive thinking in problems solving they face to improve learning and have great potential in increasing student's learning significance in the classroom (Smith, 2013; Gul and Shehzad, 2012; Jaafar & Job, 2010).

Based on preliminary observations at SMP Negeri 13 Medan, the facts also showed that students' metacognition ability were still low. The low of students' metacognition ability is also evident from the process of student's answers to storytelling diagnostic tests. Students are asked to solve the questions first then answer the questions based on student's own thinking awareness. From the results of student answers based on the test, it was seen that students were not able to solve the problem given with a complete and appropriate procedure, most students had difficulty describing the process of thinking, it had an impact on students unable to solve the problem properly. The low ability of metacognition is an important and urgent problem to be solved.

### Level of Metacognition in Problem Solving

To improve metacognition ability there is a need for awareness that students must have at every step of their thinking. But each student has different ability in dealing with problems. The level of awareness of students in thinking when solving a problem in several levels, namely *Tacit Use*, *Aware Use*, *Strategic Use*, *Reflective Use* (Schwartz & Perkins, 1989; Laurens, 2010). Chimuma and Johnson (2016) state that metacognition is an important aspect of problem solving. The problem solving steps put forward by Polya have become the basis for the development of strategies cognitive recognition, and have been widely referred to by educational researchers, especially mathematics education. All steps during the problem solving process are capability that are characteristic of metacognition. Thus metacognition is a ability needed in solving problems.

### Problem Based Learning

Problem Based Learning (PBL) has been known since the time of John Dewey. PBL consists of presenting students authentic and meaningful problems that can make it easier for them to conduct investigations and inquiry. This is in line with Gorghiu et al. (2015) said that PBL is often known as inquiry-based learning which is an effective way for students to work who can build basic ability in various domains or curricular fields. This statement is reinforced by Arends (2008b) PBL is a learning model with student learning approaches to authentic and meaningful problems to students that serve as a foundation for investment and student inquiry, so students can develop their own knowledge, develop higher ability and inquiry, students independence, and increase student confidence. According to Saragih and Habeahan (2014) PBL was one of the innovative learning models that could provided conditions for active and creative students. Abdullah et al. (2010) also stated that PBL could improved teamwork, problem solving ability and communication ability. PBL will accommodate students to construct their own knowledge based on a problem, and actively participate in making a work or product after the learning process they have passed.

Padmavathy and Mareesh (2013) stated that PBL had an effect on teaching mathematics and increasing student understanding, the ability to use concepts in real life. Furthermore, based on the results of the study of Tosun and Senocak (2013) that PBL was more effective in developing the level of metacognition awareness of students with weak background knowledge compared to those with a strong background of science. Similar to the research of Ranjanie and Rajeswari (2016) that PBL was more effective in developing metacognition awareness among students and increasing the academic potential of students in genetic learning. Merritt et al. (2017) also stated that PBL was an effective method for improving K-8 students' scientific academic achievement, including knowledge retention, conceptual development, and attitudes. Sinaga (2007) stated that five stages of PBL were (1) Orientation of students to problems, (2) Organizing students to learn, (3) Guiding individual and group investigations, (4) Developing and presenting work and (5) Analyzing and evaluate the problem solving process. From the explanation above, it can be concluded that PBL is a learning model where the learning process begins by presenting real-world or contextual problems that aim to develop a higher mindset of students, think critically and be able to solve problems presented.

### Learning Materials

Learning materials are things that must be prepared by the teacher before implementing learning. The teacher is expected to be able to design learning in order to achieve the stated educational goals (Sapta, Hamid, & Syahputra, 2018). Learning materials are materials that are needed and used in managing the teaching and learning process or a very important tool for teachers to conduct learning efficiently and to improve student learning achievement (Trianto, 2011; Olayinka, 2016).

To carry out mathematics learning with a PBL, learning materials are needed in accordance with the model. Therefore, it is necessary to develop a qualified PBL materials. In this study, the topic of materials designed is the topic of the application of social arithmetic. Furthermore, the learning materials developed

are: Learning Plans (LP), Student Books (SB), Student Worksheet (SW), Mathematical Problem Solving Ability Test (MPSAT) and Metacognition Ability Test (MAT). With the existence of a LP and SB, teaching and learning process more effective and efficient. Then SW can improve their ability to solve problems and attitudes towards mathematics (Trianto, 2011; Putra et al., 2017).

## METHOD

This study was developmental research. This developmental research used study used a Thiagarajan, Semmel, and Semmel (1974) model. which is also often referred to as 4-D which includes 4 stages, namely define, design, develop, and disseminate. Development research is conducted to get learning materials that are valid, practical, and effective (Van den Akker, 1999; Nieveen, 1999) and improve mathematical problem solving ability and metacognition ability students.

The study was conducted in SMP Negeri 13 Medan and the trial was conducted on July 30<sup>th</sup> to September 3<sup>th</sup> 2018. The subjects in this study were students of grade VII of SMP Negeri 13 Medan in the academic year 2017/2018, while the objects in this study were learning materials which was developed based PBL in social arithmetic topic. The instrument used in this study was a test. The test is used to measure students' mathematical problem solving ability and metacognition ability. Furthermore, to see the effectiveness of the learning materials, which is seen from: (1) Classical learning completeness of students at least 85% of students who take part in learning get a value of more than or equal to 2.67 in the B-letter category; (2) A minimum of 80% of the subjects studied gave a positive response to the components of the problem-based learning device developed; (3) The ability of teachers to manage learning is categorized minimal categorized quite well if it meets the criteria of  $2.50 \leq KG < 3.50$ .

Data on students' problem solving ability were obtained from the MPSAT given before and after learning using PBL devices. Data on students' metacognition ability were collected in two ways, namely through MAT and interviews. To analyze the improvement of students' mathematical problem solving ability and metacognition ability, data were obtained from the results of students' pre-test and post-test. Increasing students' mathematical problem solving ability and metacognitive ability can be obtained from normalized gain index data Hake (1999), as follows:

$$N - gain = \frac{\text{posttest value} - \text{pretest value}}{\text{ideal value} - \text{pretest value}}$$

With the normalized gain index criteria (g) shown in **Table 1**.

**Table 1.** Normalized Gain Score Criteria

Gain Score	Category
$g > 0.7$	High
$0.3 < g \leq 0.7$	Medium
$g \leq 0.3$	Low

## RESULTS

### The Description of Learning Materials Development Stage

In this study, PBL materials met the effective criteria in trial II or in other words, the draft final was obtained in trial II. The results of the development of learning materials using the Thiagarajan 4-D model are explained as follows:

#### Define

Based on observations on learning materials in SMP Negeri 13 Medan found some weaknesses in the learning materials used by teachers, because teachers have not developed LP according to student characteristics, subject matter in SB which was used by teachers and students not to present non-routine problems, does not contain contextual questions related to real life and the teacher does not use SW as support for learning activities. Furthermore, in the learning process the teacher still used conventional learning where the teacher has not used the pattern of social interaction in organizing learning students so that they are actively involved in reconstructing mathematical knowledge through mathematical problem solving derived from facts and the surrounding environment.

### Design

At this stage an initial draft of the LP is produced for 5 meetings, SB, SW, MPSAT and MAT. All results at this design stage are called draft I.

### Develop

At this stage validates draft I to experts and then conduct field trials. The aim is to see weaknesses in draft I so that it can be revised and refine the learning material developed. Expert validation results in the form of content validity assessment which shows that all learning material meets valid criteria, with a total average value of the learning implementation plan validation is 4.45, student books are 4.47, and student worksheets are 4.45. All items test students 'mathematical problem solving ability and students' metacognition ability tests meet valid and reliable criteria. Instrument reliability is used to determine test results. Based on the calculation, the reliability of the mathematical problem solving ability test is 0.908 (very high category) and the metacognition ability test is 0.852 (very high category).

After the learning device developed has fulfilled the valid criteria, then the learning device in the form of draft II is tested at the research site in SMP Negeri 13 Medan as a trial I. Based on the results of the data analysis trial, it was found that the learning device developed did not meet all the effective criteria, so that improvements are made to produce learning materials that meet all the effective criteria set. The revision is based on the findings of the weaknesses of the learning device in the trial I, namely for the learning implementation plan related to the allocation of learning time, as well as the student books and worksheets related to the material being taught. After the revision was completed, the second trial was conducted to produce learning materials that met good effectiveness and increased mathematical problem solving ability and students' metacognition ability.

### Disseminate

The development of learning materials reaches the final stage if it has obtained positive ratings from experts and through development tests. Then learning materials are then packaged, distributed and determined for a wider scale. But in this study the disseminate stage was not carried out, so the fourth stage was not explained.

### Results of Trial I

Based on the results of the trial I data analysis, it was found that the learning materials developed were not effective, because there were still several indicators of effectiveness that had not been achieved. The results of classical completeness in the mathematical problem solving ability of students in the trial I, namely at the pretest was 53.12% while the posttest was 81.25%. Classical completeness in the metacognition ability of students in the trial I, namely at the pretest was 21.86% while the posttest was 78.13%. This states that students have not fulfilled the value of classical completeness.

Indicators of effectiveness that have been fulfilled in the trial I are the positive response of students to learning material based PBL with the average percentage of positive responses of students in the trial I is 95%, and the average value of the teacher's ability to manage learning is 3.89 are categorized well.

Increasing students' mathematical problem solving ability in the first trial was seen through N-Gain from the results of the pretest and posttest mathematical problem solving ability in the trial I. From the data obtained there were no students who got an N-Gain score in the range of  $g > 0.7$  or experienced an increase in mathematical problem solving ability with the category "High", students who experienced an increase in mathematical problem solving ability with the category "Medium" or received an N-Gain score of  $0.3 < g \leq 0.7$  as many as 8 students and students who experienced increased ability mathematical problem solving with the category "Low" or get an N-Gain score of  $g \leq 0.3$  as many as 24 students. The N-gain average in experiment I was obtained 0.22 in the low category. While the increase in metacognition ability of students in the first trial obtained no students who received an N-Gain score in the range of  $g > 0.7$  or experienced an increase in the ability of metacognition in the "High" category, students who experienced increased metacognition ability in the category "Medium" or got an N-Gain score of  $0.3 < g \leq 0.7$  as many as 6 students and students who experienced an increase in the ability of metacognition in the category "Low" or got an N-Gain score of  $g \leq 0.3$  as many as 26 students. While the average N-gain in experiment I was 0.21 in the low category.

## Results of Trial II

Based on the results of the analysis of trial II data, it was found that the learning materials developed were effective based on the indicators of the effectiveness of teaching materials that had been achieved. The results of classical completeness in mathematical problem solving ability of students in the trial II, namely at the pretest was 46.88% while the posttest was 87.5%. Classical completeness in the metacognition ability of students in the second trial, namely at the pretest was 65.63% while the posttest was 87.5%. This states that students have fulfilled the value of classical completeness.

Indicator of effectiveness that has been fulfilled in trial II is the positive response of students to learning material based on problem-based learning with the average percentage of positive responses of students in trial II is 97.56%, as well as the average value of the category of teacher's ability to manage learning is 4.26 categorized well.

Improved mathematical problem solving ability of students in the trial II were seen through N-Gain from the results of the pretest and posttest mathematical problem solving ability in the trial II. From the data obtained by students who got an N-Gain score in the range of  $g > 0.7$  or experienced an increase in mathematical problem solving ability with the category "High" as many as 5 students, students who experienced an increase in mathematical problem solving ability with the category "Medium" or got a score N-Gain of  $0.3 < g \leq 0.7$  as many as 14 students and students who experienced an increase in mathematical problem solving ability in the category "Low" or got an N-Gain score of  $g \leq 0.3$  as many as 13 students. The N-gain average in experiment II was 0.41 in the medium category. While the increase in students' metacognitive ability in the second trial obtained by students who received an N-Gain score in the range of  $g > 0.7$  or experienced an increase in the ability of metacognition with the "High" category as many as 3 students, students who experienced increased metacognition ability in the category "Medium" or get an N-Gain score of  $0.3 < g \leq 0.7$  as many as 10 students and students who experience an increase in the ability of metacognition in the category "Low" or get an N-Gain score of  $g \leq 0.3$  as many as 19 students. While the average N-gain in experiment I was 0.30 in the medium category.

### Students' Metacognition Ability Level in Problems Solving

To find out the level of students' metacognition ability in problems solving, the subjects were selected to be interviewed in the category of students with high, medium, and low ability with each category as many as 3 subjects. So that the total subjects interviewed consisted of 9 students. Of the 9 subjects chosen there were subjects with many errors in answering, and there were also subjects with unique answers. Based on the analysis of the level of metacognition ability of students in solving problems in social arithmetic material, the level of students' metacognition ability is at the level of *use strategies*, *aware use*, and *tacit use*. Where as for *reflective use* level as the highest level of thinking awareness, no subject is able to reach that level. This is because students have not fully realized the thinking process and have not been able to correct the mistakes made in the steps to solving the problem. One reason for the absence of students who are able to reach this level is the age factor of students who are generally 12 years old. According to Piaget that "children aged 11-12 years enter into the stage of formal operational cognitive development" (Trianto, 2011). At this stage the child is able to apply a way of thinking to concrete and abstract problems. The scientific thinking model with what is commonly done by children is the possibility, so that in this case the child has not been able to fully realize the thinking process itself. The ability of metacognition is the highest level of ability of the four dimensions of knowledge that exists, in line with this, Panoura (2005) suggests that "it is not easy for students 'age 12' to express the process of thinking about their cognitive systems and metacognition ability" In terms of learning activities that have been going on so far, students have never been accustomed to cognizance in learning activities. So it is very natural that no student can reach that level.

## DISCUSSION

From the description above, it was found that learning by using PBL materials improved students' mathematical problem solving ability and metacognition ability in trial II. The results of this study are in accordance with the results of device development research obtained by Aufa et al. (2016) which showed that the completeness of learning outcomes of students who obtained PBL showed an increase from trial I to trial II for mathematical communication ability. The results of this study are also in accordance with the results of research by Amalia et al. (2017) stated that "the result showed PBL learning is effective in improving the ability of mathematics problem solving for students". Jaisook et al. (2013) also said that PBL is effectively

used in mathematics learning and can improve students' understanding and ability to apply mathematical concepts in everyday life. With the existence of PBL students can be free to develop their creativity and problem solving ability (Karaduman, 2013). Muraray-Harvey et al. (2013) stated that a broader PBL process could create opportunities to develop meaningful knowledge, attitudes and ability related to collaborative learning, so as to build collaborative knowledge that is effective, helping students to make explicit the relationship between attitudes towards collaboration and achieving learning outcomes, and identifying specific collaborative ability needed by students, and obtained through the results of group collaboration. PBL contributes to student development (Tan et al., 2015). Thus, if thinking is an important thing in education, then ways must be found to help individuals develop their ability. That is, in this learning students are expected to be able to solve problems from things that have been understood and that are in his mind to build a knowledge obtained.

Development of learning materials that provide results of improving students' metacognition ability is also in accordance with the results obtained by Aliyu et al. (2016) stated that the "significant effects of the PBL approach on participants' awareness of metacognition knowledge of task requirements, personal learning process, use strategy, text and accuracy, problem solving and discourse features. The findings revealed that the nature of the structured problem, which is related to their real life, and the interactions during the PBL, increased the participants' awareness of metacognitive knowledge. In line with that Amin and Sukestiyarno (2015) stated that "There is a positive effect of metacognition awareness of students' cognitive ability of students influenced by metacognition awareness". Mustafa et al. (2017) also stated that PBL materials developed could improve students' metacognition ability.

In problems solving, students' metacognition ability also play a role so students can think of mathematical ideas in problems solving. Metacognition is also the process by which a person thinks about thinking in order to develop strategies to solve problems. As the results of Jayapraba (2013) study which states that "metacognition as thinking about thinking, which is thinking about thinking. In simple terms metacognition can be interpreted as an awareness of thinking about the thought process. Metacognition ability that is owned by a person can be categorized into 4 levels of ability, namely *strategic use, aware use, tacit use and reflective use*. These four levels are related to the stages in problems solving. As stated by Chimuma and Johnson (2016) stated that: "metacognition is an important aspect in problem solving". Muir et al. (2008) stated that "at the stage of implementing the plan, good problem solvers are able to implement their plans and demonstrate metacognition thinking ability during the implementation of the plan, and are able to re-examine the settlement at the time or after implementing the plan". But based on the results of the analysis of the level of metacognition ability of students in solving problems in social arithmetic topic, the level of students' metacognition ability is only at the level of use strategies, aware use, and tacit use. Whereas for reflective use level as the highest level of thinking awareness, no subject is able to reach that level. This is because students have not been able to fully realize the thinking process, have not been able to correct the mistakes made in the steps to solve the problem and are still hesitant to ask the teacher in the learning process. The learning process will be better if there is a more tangible interaction between students and teachers (Sapta, Hamid, & Syahputra, 2018).

## CONCLUSION

From the discussion above, it can be concluded that mathematical problem solving ability and metacognition ability of students experience is improved after learning using PBL materials. This research shows that mathematics learning is an important matter to be considered in an effort to maximize student mathematics learning achievement. Thus, it is expected that mathematics teachers can use this learning models by making qualified learning materials in mathematics learning at school.

## Disclosure statement

No potential conflict of interest was reported by the authors.

## Notes on contributors

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