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Developing Critical Thinking Skills of Students in Mathematics Learning

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Abstract

Critical thinking skills should be part of student's learning and schools should be responsible to develop and evaluate critical thinking skills through teaching and learning process. This study aims to investigate the effects of mathematical learning modules based on PBL to critical thinking skills in mathematics at secondary school students in District of Bone. Assessment of critical thinking skills in non-routine mathematical problem solving includes three parts; namely the identification and interpretation of information, information analysis, and evaluation of evidence and arguments. This study involved a total of 68 students grade 12 science state secondary school (SMAN) in Bone District of South Sulawesi, Indonesia in academic year 2014-2015. The sample consists of 38 students in the city and 30 rural students. The design of the study was quasi experimental with one group pretest-posttest. The data was analysed using the inferential t-test with SPSS 20.0. Result of the study found that there are positive effects of the use of mathematical learning module based on PBL to enhance the ability of critical thinking skills in mathematics students in all three components, namely, identification and interpretation of information, information analysis, and evaluation of evidence and argument.

Keywords: *mathematical critical thinking skills, module based on PBL, non routine problem*

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Introduction

Efforts to develop the critical thinking skills of mathematics have become the main agenda in the curriculum of mathematics education worldwide (NCTM, 2000; Mason, Burton and Stacey, 2010; Innabi and Sheikh, 2006). Many researchers have shown that the development of critical thinking skills can improve mathematics achievement (NCTM, 2000; Silver & Kenney, 1995; Semerci, 2005; Jacob, 2012; Chukwuyenum, 2013). Similarly, critical thinking skills will encourage students to think independently and solve problems in school or in the context of everyday life (NCTM, 2000; Jacob, 2012). The education system in Indonesia is still focused on the exam. Therefore practice of teaching focuses on subject content and ignore the development of students' thinking skills (Soedjadi, 2000; Rohaeti, 2010). Most of the teaching and learning process that takes place in school is the lecture method, which is based on memorization of facts that leads students to think less critical (Cobb et al., 1992; Duplass and Ziedler, 2002). Thus, negligence of the importance of thinking skills in teaching and learning affects students' ability to think (Henningsen & Stein, 1997; Zohar & Dori, 2003). This leads to students' thinking ability in Indonesia is in low level. Low ability among Indonesian students is shown by the study TIMSS 2011 and PISA 2012. Study Trends in Mathematics and Science Study (TIMSS 2011) to form two secondary school students showed that students of Indonesia ranked 38th in mathematics from 42 countries (Mullis *et al.*, 2012). While, the results of PISA 2012 survey found Indonesian students at position 64 of the 65 countries in mathematical literacy skills (OECD, 2014). The study revealed that Indonesian students' answer efficiently in arithmetic problem but weak in non-routine problem solving involving revelations, give opinions and make reasoning. This finding has prompted the Ministry of Education of the Republic of Indonesia to strengthen efforts to improve the quality of mathematics learning in school.

According to Facione (2011) the most basic concept of critical thinking is the ability of interpretation, analysis, evaluation, inference, explanation and self regulation. While critical thinking skills by Onosko and Newmann (1994) may challenge the students to interpret, analyze or manipulate information. Therefore, the critical thinking skills needed when we try to understand something of information that will be used for the triggering of ideas (Ennis, 1996). Similarly, critical thinking requires a student to use new information or manipulate existing knowledge and information so as to obtain reasonable responses to new situations (Lewis and Smith, 1993; Perkins and Murphy, 2006). Ennis (1996) opined that critical thinking is reflective thinking that focused on patterns of decision making about what must be believed and what must be done. In the context of mathematical problem solving, Krulik and Rudnick (1995) stated that critical thinking is analytical thinking and reflection that involving testing activities, questioning, connecting and evaluating all aspects of a situation or problem. Critical thinking skills are very important in mathematics learning, because these skills can improve the quality of mathematics learning in better and meaningful, so therefore should be a systematic way to develop such skills through mathematics learning in school (Cobb et al., 1992).

The goal of developing thinking skills is to have a quality of thought, in which the quality of thinking is required not only in school but also outside school (McGregor, 2007). Thinking skills related to the students' ability to understand the thought process when studying the subject content (Swartz, 2001). Therefore, students should not only understand the content of mathematics but also the process of mathematical thinking (Cobb et al., 1992; Rajendran, 2010). Many educators argue that thinking skills can be learned and should be taught explicitly and students should be informed about the types of thinking skills taught to them (Swartz, 2001; McGregor, 2007). Research shows that students' thinking skills can be developed if teachers create a classroom environment that supports the thinking activities (Swartz and Parks, 1994; Rajendran, 2010; Mason, Burton and Stacey, 2010). Teachers do not necessarily dominate and control the learning activities but should encourage students to take an active role and demonstrate good multilateral interaction between teacher and student or student to student interaction (Henningsen & Stein, 1997).

There are two different methods in developing thinking skills, some researchers believe that thinking skills can only be taught separately (Lipman, 1985), while some other researchers believe that thinking skills can be infused in school subjects (Swartz, 2001; McGuinness et al., 2003; Rajendran, 2010). Based on the state curriculum in schools today, the proposed method for teaching thinking skills are infusion method (Rajendran, 2010). It is supported by Swartz (2001) and Butera *et al.* (2014) which stated that a more effective teaching thinking skills in the context of the subjects because integrating thinking skills in teaching is a natural way for teachers to teach students how to think.

Mathematics is one of the subjects that can develop critical thinking skills is (Rajendran, 2010; Aizikovitsh & Amit, 2010). Critical thinking skills in mathematics is the process of critical thinking with related to knowledge of mathematics, mathematical reasoning and mathematical proofs in mathematical problem solving (Krulik and Rudnick, 1995). In this study, evaluation of critical thinking

skills in mathematics using three components, namely (1) identification and interpretation of information, (2) information analysis, and (3) evaluation of evidence and argument (Krulik and Rudnick, 1995; Glazer, 2001; Ennis, 1996; Facione, 2010).

Problem Statement

Low ability among Indonesian students is shown by the study TIMSS 2011 and PISA 2012. The study found that Indonesian students could answer arithmetic problems but they are sufficiently weak to solve non-routine problems involving revelations, giving opinions and making reasoning. One of the low ability of Indonesian students in non routine problems solving is the lack of emphasis on the development of critical thinking skills in mathematics learning. Thus, critical thinking skill can be developed through a process of mathematics learning because mathematics has a structure and a strong and clear connectivity between its concepts to students who learn mathematics potential to be rational, logical thinking and critical (Rajendran, 2010; Aizikovitsh and Amit, 2011). Critical thinking skills in mathematics closely related with problem solving in mathematics, as with mathematical open-ended problems and contextual problem will challenge students to solve the problem up to encourage students to mathematical thinking (Henningsen & Stein, 1997; NCTM, 2000).

Efforts should be made on an ongoing basis using various methods and appropriate learning methods in developing the critical thinking skills (Rajendran, 2010). One method that can help students to develop critical thinking is a method of problem-based learning (PBL) (Krulik & Rudnick, 1995; Herman, 2006). This method gives students the opportunity to make the exploration, investigation and problem solving (Arends, 2007; Gallagher, 1997). Therefore, PBL was believed to help students generate new knowledge and also encourage students to think critically through a variety of processes to solve problems. Mathematics learning can develop critical thinking skills in mathematics require complex mathematical tasks that can encourage higher order thinking skills (Henningsen & Stein, 1997). High level mathematics problems that involve thinking, analysis, synthesis can stimulate students' critical thinking skills (Krulik & Rudnick, 1995; Aizikovitsh & Cheng, 2015). Thus the complex problem-solving activities will enhance students' understanding and can apply the knowledge built in the new situation (Henningsen & Stein, 1997). Most of the teachers use the textbooks only that involve low-level thinking skills such as memorizing facts (Tobin & Gallagher, 1987). Therefore, there is necessary learning material covering complex issues to support the development of mathematical critical thinking skills in the classroom.

Research Questions

1. What is the level of students' critical thinking skills in mathematics before and after implementing of learning modules based on PBL?
2. Are there significant differences between students' ability in critical thinking skills in mathematics to the component of identification and interpretation of information before and after implementing of learning module based on PBL?
3. Are there significant differences between students' ability in critical thinking skills in mathematics to the component of information analysis before and after implementing of learning modules based on PBL?
4. Are there significant differences between students' ability in critical thinking skills in mathematics to the component of evaluation of evidence and argument before and after implementing of learning module based on PBL?

Method

This study used a quasi-experimental method and a design used is the design of pretest and posttest were not random (Creswell, 2012). Taking into account factors internal validity and external validity of this experimental study, it was expected that the results of the study confirmed as a result of treatment based learning problem (Creswell, 2012). This research aims to determine the effect of learning modules based on PBL to students' critical thinking skills in mathematics. This study used independent variables learning modules based on PBL, while the dependent variable was the critical thinking skills of mathematics. The population was a Grade 12 first session students of Science Program Secondary School (SMAN) in academic year 2014-2015 of Bone area, South Sulawesi. This population was chosen with consideration that based on Piaget's theory of mental development; a grade 12 student has a level of formal operational thinking. So, it can be taught critical thinking skills of mathematics

(Ormrod, 2008). However, individual cognitive development was also influenced by the social environment (Vygotsky, 1978). To determine the sample, purposive sampling technique namely a secondary school in the City (SMAN 2 Watampone) and a rural secondary schools (SMAN 1 Tellu Siattinge) was used. From both schools, a grade 12 science class at school in the city and a grade 12 science classes in rural schools as the treatment group were selected.

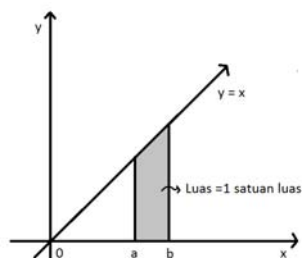
Mathematical Learning Module Based on PBL

According to constructivism, knowledge is not passively received but actively built by students (Glasserfeld, 1987). In this module, teachers do not teach mathematics knowledge by lecture, but students should be actively involved in the problem solving process. Activities in mathematical learning modules based on PBL, can include individual investigation, collaborative investigation and presentation of assignments (Arends, 2007). Individual investigative activities encourage students to explore non routine mathematics problems that can develop critical thinking skills (NCTM, 2000). While the collaborative activities can provide training to share ideas, communicate and convince others about mathematics problem solving strategies. Encouraging students for communication and interaction with other people is very important to build critical thinking skills (Abrami et al., 2008; Jacob, 2012). Next, through the presentation of assignments, students can practice and get used to speaking in public with confidence to communicate ideas (Arends, 2007). When the role of teachers is facilitators rather than teachers (Arends, 2007). Thus, students are expected to be independent, self-control and assess their thinking (Facione, 2011). Students are taught to have the ability to identify and analyze the information in a situation, especially the situation that are complex and ambiguous, and students are able to analyze the information to assess the justification. Therefore, the activities of students in the module can encourage students to identify and interpret information, analysis, information and evaluation of evidence and arguments.

Mathematical content in mathematics module not only explain the procedures or the use of formulas in mathematical problems solving, but also aims to provide a deep understanding of the concept of integration and develop students' critical thinking skills. Newman *et al.* (1989) stated that teachers give task to the students are not to determine the failed/passed for the student but to observe and analyze the views of students and how teachers should guide students so successfully complete the task.

Examples of the questions in the module on the topic of integration

Given a region bounded by $y = x$, the x-axis, the line $x = a$ and $x = b$.



- Determine the values of a and b so that the shaded area is 1 unit area
- Compare your answers with other student
- Discuss to find the pattern of answer

This problem will encourage the students to do investigation, share ideas in interpreting the information, analyze information and evaluate of evidence and argument of the students.

Assessment Instrument of Critical Thinking Skills in Mathematics

The purpose of assessment instruments of critical thinking skill in mathematics was to measure students' critical thinking skills in non-routine mathematical problem solving. Evaluation of critical thinking skills in mathematics must be paid attention to students' thinking processes while solving problems in mathematics, not just the result of the answer. So that the instrument is not only evaluate mathematical knowledge but more importantly to assess the level of critical thinking. Components of critical thinking skills in mathematics can be measured by three, namely (1) the identification and interpretation of information, (2) information analysis, and (3) evaluation of the evidence and arguments (Krulik and Rudnick, 1995; Glazer, 2001; Ennis, 1996; Facione, 2011). Therefore, to develop critical thinking skills in mathematics learning is also necessary to make assessment instruments of component of critical thinking associated mathematical context. Assessment instruments of critical thinking skills in mathematics for pretest and posttest covered four non routine mathematics problems. Pretest constructed by reference from previous mathematics topics. While, the posttest constructed by reference

from the topics of integration. To evaluate each component of critical thinking skills of mathematics, this study used critical thinking skills assessment rubric which was adapted from holistic critical thinking scoring rubric (Facione & Facione, 1994) using a score of 0, 1, 2, 3 and 4 in accordance with the ability of critical thinking skills of students. Meanwhile, to obtain a level of critical thinking skills of mathematics used Marking the Ministry of Education as follows:

Table 1. The Range of Score in Critical mathematics thinking skills (Ministry of Malaysia Education)

Range of Score %	levels of students' critical thinking skills
80 – 100	Excellent
60 – 79	Good
40 – 59	Fair
20 – 39	Poor
0 – 19	Very Poor

Meanwhile, in order to assess the validity and reliability of the instruments the following procedure was used. Before the assessment instruments used critical thinking skills of mathematics, first, it was approved by three experts on mathematics education to see the content validity and face validity in accordance with the recommendations Gable and Wolf (1993). Based on the recommendations of the experts, some parts of the instrument repaired, then a pilot study was done on a group of students. Through the analysis of student responses in the pilot study obtained the discrimination index, facility index and reliability of the instrument. According to Mok (1994), facility index is used to indicate whether the questions are too hard, too easy or simple. Based on table 2, the facility index on questions instrument all be in the range $0.30 \leq A \leq 0.80$ (at a moderate level), so the question is in admissible (Mok, 1994). Discrimination index refers to the ability of items of assessment instruments can distinguish high achievers from low achievers. According to Mok (1994) discrimination index ≥ 0.40 is at a high level of positive discrimination so that the appropriate instruments are received. The results of the pilot study instruments described in table 2 below.

Table 2. Validity and Reliability of Instrument of critical thinking skills in mathematics

Validity and Reliability	Pretest Instrument				Posttest Instrument			
	Item 1	Item 2	Item 3	Item 4	Item 1	Item 2	Item 3	Item 4
Discrimination Index	0.711	0.489	0.667	0.511	0.400	0.420	0.400	0.420
Facility Index	0.526	0.549	0.571	0.469	0.519	0.481	0.568	0.492
Reliability scale	0.906				0.954			

While the reliability of the instrument refers to the stability and internal consistency of the questionnaire (Creswell, 2012). Therefore, reliability of critical thinking skills assessment instruments shaped mathematical subjective test to measure the internal consistency of a construct, it was measured using Cronbach alpha (Creswell, 2012). According to table 2, reliability scale of pretest instrument was 0.906 while reliability scale of posttest instrument is 0.954. Sekaran (1992) and Creswell (2012) stated that Cronbach alfa value above 0.80 is considered good.

Data Analysis and Findings

Data experimental study pretest and posttest measured instruments critical thinking skills using non-routine mathematics problems. It is analyzed into two parts; descriptive analysis and inferential analysis as follows.

1. Descriptive Analysis

Results from the data analysis on the pretest in table 3 show that the ability of critical thinking skills of students in component of identification and interpretation of information has mean = 11.720 (73.25%) at a good level; while, the ability of critical thinking skills of students in information analysis component has mean = 7.820 (48.88%) at fair level, and the ability of critical thinking skills of students in evaluation of evidence and argument component has mean = 7.070 (44.19%) at fair level. Overall, ability of critical thinking skills in mathematics of students in pre-test derived from the mean of the three components of critical thinking skills was 55.44%. According to the marking of Malaysian

Ministry of Education that level critical thinking skills of students before implementing learning modul is at a fair level.

The findings on the posttest showed that the ability of critical thinking skills of students in component of identification and interpretation of information has mean = 12.990 (81.19%) at an excellent level. The ability of critical thinking skills of students in information analysis component has mean = 10.650 (66.56%) at good level, and the ability of critical thinking skills in component of evaluation of evidence and arguments has mean = 9.130 (57.06%) at a fair level. Overall, ability of critical thinking skills in mathematics of students in posttest derived from the mean of the three components of critical thinking skills was 68.27%. According to the marking of Malaysian Ministry of Education that level critical thinking skills of students after implementing learning modul is at a good level.

Table 3. Mean, standard Deviation for Pretest and Posttest score of Critical Thinking Skills

Test	Component of Critical Thinking Skills	N	Maximum Score	Mean	Standard Deviation
Pretest	Identification And Interpretation of The Information	68	16	11.720 (73.25%)	3.227
	Information Analysis	68	16	7.820 (48.88%)	3.407
	Evaluation of Evidence And Arguments	68	16	7.070 (44.19%)	3.206
Posttest	Identification And Interpretation of The Information	68	16	12.990 (81.19%)	2.397
	Information Analysis	68	16	10.650 (66.56%)	2.941
	Evaluation of Evidence And Arguments	68	16	9.130 (57.06%)	3.138

2. Inferential Analysis

To examine the significant differences between students' ability of critical thinking skills in mathematical on three components, namely the identification and interpretation of information, information analysis and evaluation of evidence and arguments used t-test statistical analysis with SPSS 20.0, as the entire data meets the requirements of normality tests (Tiro, 2001).

Comparison of Performance between Pretest and Posttest Scores on Component of Identification and Interpretation of Information

Data analysis for comparison mean between pretest and posttest scores on the component of identification and interpretation of information can be summarized by table 4. Table 4 shows that the increase in scores of pretest and posttest is 1.27. T test showed that significant difference in mean improvement between pretest and posttest (Sig. <0.05). Therefore, the null hypothesis says that there are no significant differences between students' ability in critical thinking skills in mathematics to the component of identification and interpretation information on the pretest and posttest is rejected. It means that there are significant differences between students' ability in critical thinking skills in mathematics to the component of identification and interpretation of information before and after implementing of mathematical learning modules based on PBL.

Table 4. Comparison of performance between pretest and posttest scores on component of identification and interpretation of information

Test	N	Maximum score	Mean	Standard Deviation	Mean difference Posttest-Pretest	Value of sig.
Pretest	68	16	11.72	3.227	1.27	0.001
Posttest	68	16	12.99	2.397		

Comparison of Performance between Pretest and Posttest Scores on Component of Information Analysis

Analysis of data on mean performance comparison between the pretest and posttest scores on the component information analysis can be summarized by table 5. Table 5 shows that the increase in scores of pretest and posttest is 2.83. T test showed that a significant difference in mean improvement between pretest and posttest (sig. <0.05). Therefore, the null hypothesis which says that there are no

significant differences between students' ability in critical thinking skills in mathematics to the component of information analysis of student on the pretest and posttest is rejected. It means that there are significant differences between students' ability in critical thinking skills in mathematics to the component of information analysis before and after implementing of mathematics learning modules based on PBL.

Table 5. Comparison of performance between pretest and posttest scores on the component of information analysis

Test	N	Maximum Score	Mean	Standard Deviation	Mean difference Posttest-Pretest	Value of sig.
Pretest	68	16	7.82	3.407	2.83	0.000
Posttest	68	16	10.65	2.941		

Comparison of Performance between Pretest and Posttest Scores on the Component of Evaluation of Evidence and Arguments

Analysis of data on the mean performance comparison between the pretest and posttest scores on the component of evaluation of evidence and arguments can be summarized by table 6. Table 6 shows that the increase in scores of pretest and posttest is 2.06. T test showed that significant difference in mean and improvement between pretest and posttest (sig. <0.05). Therefore, the null hypothesis states there are no significant differences between students' ability in critical thinking skills in mathematics to the component of evaluation of evidence and arguments on the pretest and posttest is rejected. It means that there are significant differences between students' ability in critical thinking skills to the component of mathematics in evaluation of evidence and arguments before and after implementing of learning modules based on PBL.

Table 6. Comparison of performance between pretest and posttest scores on component of evaluation of evidence and arguments

Test	N	Maximum Score	Mean	Standard Deviation	Mean difference Posttest-Pretest	Value of sig.
Pretest	68	16	7.07	3.206	2.06	0.000
Posttest	68	16	9.13	3.138		

Discussion

Based on descriptive analysis, it was found that the level of critical thinking skills before implementing of learning module based on PBL was at fair level, and the level of thinking skills after implementing of learning module based on PBL was at good level. Therefore, PBL provides the effect of increasing the critical thinking skills of students. The findings of this research are consistent with the findings of previous studies that PBL can assist students in the development of critical thinking skills of mathematics (Rohaeti, 2010; Herman, 2006). It is supported by Arends (2007) that the PBL can support the investigation and the inquiry, so that PBL could potentially build critical thinking skills. Furthermore, this study of inferential analysis will be discussed in detail in the following paragraphs.

Critical Thinking skills in Mathematics

Component of Identification and Interpretation of Information

The results of this study show that learning modules based on PBL effectively help students develop critical thinking skills in mathematics to the component of identification and interpretation of information. Findings of inferential analysis using the t-test is obtained that there are significant differences between component of identification and interpretation of information before and after learning of mathematics that uses modules based on PBL. This study supports the findings Sabariah (2003) that PBL can enhance critical thinking skills in component of interpretation information. Various activities in the module that can encourage this component is non routine problem solving. On non routine problem solving, students try to look for information on given problem and provide interpretation and associate with various concepts needed to solve the problem. On a process of interaction between students, reflection and problem solving in PBL activities can encourage students to

develop critical thinking skills (Savery and Duffy, 2001), especially component identification and interpretation of information.

Component of Information Analysis

The results of this study show that learning modules based on PBL effectively helps students develop critical thinking skills in mathematics to the component of information analysis. Findings of inferential analysis using the t-test is obtained that there are significant difference between the component of information analysis before and after learning of mathematics that uses modules based on PBL. On non-routine problem solving in modules based on PBL, students try to explore issues of information and analysis of the information to plan strategy to solve the problem based on the information obtained to solve the problem (Krulik and Rudnick, 1995).

Component of Evaluation of Evidence and Argument

The results of this study show that learning modules based on PBL effectively help students develop critical thinking skills in mathematics to the component evaluation of evidence and arguments. Findings of inferential analysis using the t-test is obtained that there are significant differences between the component of evaluation of evidence and arguments before and after implementing learning modules based on PBL. Various activities in the module that can encourage a component of which is the investigation has non routine problem solving individually or collaboratively. On individual investigations, students are responsible for solving problems with the processes of self-evaluate their solution procedures. On the other hands collaborative investigation, the students can share with other students to mutually evaluate the evidence and arguments in solving problems. Thus, the communication and persuading others to improve critical thinking skills (Abrami *et al.*, 2008) is the ability to assess the argument in the solution to the problems of the various supported reasonable arguments from students.

Conclusion

The results show that the learning module based on PBL is an effective method to develop critical thinking skills in mathematics on component of identification and interpretation information, information analysis and evaluation of evidence and argument. Critical thinking skills are necessary for students to succeed in the future. Therefore, the skills of critical thinking should be applied and developed in core curriculum and teaching and learning process to produce students who have quality thinking future leaders. Therefore, it is very important to develop students' critical thinking skills in all lessons subjects, especially mathematics. Mathematics learning not only teaches mathematical content but also develop students' critical thinking skills that are necessary for students to solve various problems in school or in social life.

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