Increasing Mathematical Critical Thinking Skills Using Advocacy Learning with Mathematical Problem Solving

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Abstract. *The ability to think critically is one of the abilities students must possess. Students' critical thinking skills have not been encouraging. There is a need for learning that can improve this ability, one of which is advocacy learning. The study aims to increase students' critical thinking skills with open-ended mathematical problems in advocacy mathematics learning. This study is a nonequivalent control group design with a pre-test post-test control group. Sampling using cluster random sampling, randomization was carried out in classes at Junior High School 4 Bandung by taking two classes. Data analysis used Mann-Whitney, one-way ANOVA, and Tukey. The results showed that students treated with an advocacy approach by giving open-ended questions had better mathematical critical thinking skills than those who received conventional learning. Also, students with high prior knowledge had better critical thinking skills compared to the other two groups. This research implies that the advocacy can be used as an alternative to learning mathematics for students with high prior knowledge.*

Keywords: critical thinking, advocacy, open-ended problem

Introduction

Self-regulation to decide something that results in interpretation, analysis, evaluation, inference, and exposure using evidence, concepts, methodologies, criteria, or contextual considerations that form the basis of decision making is often referred to as critical thinking (Facione, 2016). Critical thinking is the skill of reflection focused on what is believed or done (Ennis, 1996) and high-level cognitive information processing (Choy & Cheah, 2009). Critical thinking skills include basic classification skills, basic decision making, concluding, providing a further explanation, estimation, and integration, as well as additional skills (Briars & Larkin, 1984). Critical thinking is a process for making reasonable, logical, and well-thought-out judgments. Besides, critical thinking is a concept to respond to a thought or theorem that we receive. The response involves the ability to systematically evaluate and think clearly and rationally about what to do or what to believe. In the context of this research, critical thinking is a skill in deciding something using mathematical evidence, mathematical concepts, methodology in mathematics, or mathematical criteria.

Critical thinking is one of the skills that focus on mathematics learning besides creative thinking and the skill to solve problems (Kalelioğlu & Gülbahar, 2014; Sutrimo, Kamid, & Saharudin, 2019; Widodo, Turmudi, & Dahlan, 2019). Critical thinking skills are needed by students to deal with mathematical problems (Peter, 2012) and face challenges in social life (Fakhriyah, 2014). However, critical thinking skills are rarely trained by the teacher (Santrock, 2011) since the teachers always motivate students to give correct answers. Mathematics teachers will look angry if students are unable to provide correct answers; even new ideas raised by students to solve problems are always questioned for their validity by the teacher (Bada & Olusegun, 2015; Dagar & Yadav, 2016; Kim & Tan, 2011). In addition, the habits of teachers who ask students to retell, define, describe, and register (Conner, Singletary, Smith, Wagner, & Francisco, 2014; Powell, Fuchs, & Fuchs, 2013), rather than analyze, draw conclusions, connect, synthesize, criticize, create, evaluate, think and rethink (Asmara, Massawet, & Rambitan, 2016; Shanti, Sholihah, & Martyanti, 2017), cause students' critical thinking skills to be not optimal. As a result, students' critical power related to solving math problems becomes weak (Moore & Carlson, 2012) because students' critical thinking skills are not trained during the learning process. The low critical thinking skills of students are evident from the results of the 2015 Trends in International Mathematics and Science Study (TIMSS), which shows that Mathematics scores are ranked 45 out of 50 countries (Mullis, Martin, Foy, & Hooper, 2016). The reasoning realm also indicates that this ability is still very minimal (Sumarmo, Hidayat, Zukarnaen, Hamidah, & Sariningsih, 2012).

In order to develop student's critical thinking skills, a teacher is expected to create an interactive classroom atmosphere, students are seen as thinkers, not someone who is taught, and the teacher acts as a mediator, facilitator, and motivator who helps students in learning not teaching (Nuryanti, Zubaidah, & Diantoro, 2018). In addition, to create an interactive learning atmosphere, a teacher can encourage students to listen to authentic materials, involve students in joint assignments, create a different room atmosphere, provoke students to issue in the brain, and take advantage of technology. One learning approach that teachers can use to improve students' critical thinking skills is to use advocacy learning. This approach is student-centered learning and is often identified with the debate process (Fox & Wiens, 2019). Advocacy learning is an alternative approach to learning that can be used by mathematics teachers so that students can be actively involved in the learning process in mathematics classrooms (Fox & Wiens, 2019; Haryanto & Suhartono, 2019). Student activities in advocacy learning are carried out by submitting opinions and arguments about solving math problems given by the teacher through the debate process (Tandililing, 2013). Advocacy learning is a learning approach that invites students to be active in learning activities. Hence, it is hoped by using an advocacy

learning approach, students' learning outcomes are improved, and students can actively participate in debates so that the critical power of students in mathematics will continue to be properly trained.

Advocacy learning has been widely used in civic education, social science, or subjects with the same characteristics as the two subjects (Lisnawati, 2020; Sumarwoto, 2019). The characteristics of the advocacy include the existence of debates between students on predetermined topics, topics that are considered essential to students, topics that are tailored to the interests and needs of students. The advocacy learning can be adopted in exact sciences such as mathematics. This adaptation is carried out by providing mathematical problems to students. It is hoped that students will be able to analyze information, evaluate information, formulate questions, ask questions, gather information, assess relevant information, be open-minded, and communicate effective mathematical results (Chen & Hu, 2018; Zhou, Jiang, & Yao, 2015), so that students' critical thinking skills are better (Nurhasanah & Julyanti, 2019). This result follows the results of previous research, which states that giving math problems can improve students' skills in solving math problems and develop students' critical thinking skills (Haryani, 2012).

Research in mathematics education about advocacy learning associated with mathematical abilities has been widely carried out. For instance, research connects advocacy to solve mathematical problems (Nurhasanah & Julyanti, 2019) and mathematical connection abilities (Hartini, 2018; Rinzani, 2017; Tandililing, 2013). On the other hand, there is limited research in mathematics education about advocacy learning with critical thinking abilities (e.g., Sinaga, 2013). However, the study of Sinaga (2013) has not provided information about which learning process has the best effect on aspects of critical thinking skills. This study does not relate to students' prior knowledge as one of the researches focuses. The outcomes obtained from this study could be influenced by the students' prior knowledge. As previously stated, by giving mathematical problems in advocacy learning, students can analyze and evaluate information, ask questions, collect, formulate, and assess information so that students' critical thinking skills are better. Therefore, it is necessary to increase mathematical critical thinking skills using advocacy learning with mathematical problem-solving. This research not only links critical thinking skills, mathematical problem solving, and advocacy learning, but also links with students' prior knowledge. Based on these problems, the formulation of the issues in this study includes whether there is an increase in critical thinking skills at each level of the initial ability of students who use advocacy learning with open-ended problems?

Method

The present study is a quasi-experimental study with a non-equivalent control group design (see Table 1). The research design used a pre-test post-test control group (Cohen, Manion, Lecturer, Morrison, & Lecturer, 2007). The activities carried out in this study have four phases, namely: (a) the initial phase, including determining the research sample, preparing pre-test questions, developing learning tools, compiling post-test questions; (b) the planning phase, including setting a schedule for conducting research; (c) the implementation phase of the activity, including conducting the pre-test, carrying out learning in the control and experimental groups; and (d) the final phase of the activity, including conducting a post-test, processing data, and interpreting the results of data analysis.

Table 1. Research design

Group (Class)		Pretest	Independent Variable	Posttest
R (Random)	E (Experiment)	Y1	X (treatment)	Y2
R (Random)	C (Control)	Y1	-	Y2

This study's population were all eighth-grade students of Junior High School 4 Bandung, which were divided into ten classes, and every class generally had 36 students. The school has divided students into ten classes randomly so that researchers cannot intervene in dividing groups of students into several classes. However, the school said that, in general, each class has the same cognitive abilities. With this condition, the cluster random sampling technique based on the classes that have been formed can be used to take the research sample. By taking two of the ten existing classes, the researchers used them as the control and experimental groups. Advocacy learning and open question debriefing were applied to the experimental group, while conventional mathematics learning was tested in the control group. The balance test's statistical results in the two classes showed that the t count was 0.035 with a significance coefficient of more than 0.05. Therefore, statistically, both classes have the same cognitive abilities.

There are two research instruments used, critical thinking tests and prior knowledge tests. Critical thinking tests were given before treatment (pre-test) and after treatment (post-test) to both sample groups. This test consists of 10 items about mathematics, especially in the topic of set, with validity results of more than 0.622 for the pre-test and more than 0.766 for the post-test. The reliability calculation result for the pre-test is 0.90, and the reliability calculation for the post-test is 0.85. The scoring rubric of students critical thinking skills refers to indicators: (1) students' skill to identify and justify concepts, namely the skill to give reasons for mastery of concepts; (2) the skill of students to generalize, namely the skill to complete supporting data or information; and (3) the skill of students to analyze algorithms, namely the skill to evaluate or examine an algorithm (Ku, 2009; Wardani, Lindawati, & Kusuma, 2017).

The prior knowledge test aims to determine students' ability to understand basic mathematics. This test was given before the treatment was given to two groups. This study's basic mathematics is the concept of set. In other words, prior knowledge is used as a pre-requisite for studying the concept of set. This test was prepared by a mathematics teacher at Junior High School 4 Bandung. Teachers are involved in making this test because they understand better students' cognitive knowledge than the researchers. Also, by involving the teacher in compiling this test, there was no error in grouping students based on their initial ability level. The grouping of prior knowledge levels refers to Table 2.

Table 2. Level of prior knowledge

Levels	Criteria
High	$X \geq \bar{x} + s$
Medium	$\bar{x} + s > X > \bar{x} - s$
Low	$X \leq \bar{x} - s$

Note X = scores of students' critical thinking skills
$\bar{x}$ = mean of students' critical thinking skills
s = deviation standard of critical thinking skills

In general, the analysis technique in this research used normalized gain data (N-Gain). The steps used to carry out the analysis are: first, determine descriptive statistics. Descriptive statistics were carried out by determining of mean, variance, and standard deviation for each data group to obtain an overview for each data group in this study. Second, inference statistics by applying one-way ANOVA. This test also looks at the assumptions or conditions that must be met before carrying out statistical tests. Normality and homogeneity of variance is the assumption test used for one-way ANOVA. If one of the assumptions cannot be fulfilled, then one-way ANOVA cannot be used, so it must use statistical non-parametric analysis such as the Mann-Whitney test (Martin & Games, 1977).

Results and Discussion

The data processing of students' mathematical critical thinking skills at Junior High School 4 Bandung in the experimental and control groups is described in Table 3.

Table 3. Students' mathematical critical thinking skills

Group	Pre-test		Post-test		N-Gain (%)	
	Mean	Stand. Dev.	Mean	Stand. Dev.	Mean	Stand. Dev.
Experiment	8.99	4.19	21.49	6.27	48.80	22.93
Control	10.10	3.81	13.47	4.64	13.84	12.01

Table 3 is the result of the descriptive calculation of students' mathematical critical thinking skills. In general, the study found that the average of critical thinking skills of the experimental group both in the pre-test and post-test was better than that of the control group.

Likewise, for the N-gain, the experimental group had an average N-Gain of 48.80, and the control group was 13.84.

In order to achieve the study objectives, the data analyzed were N-Gain at mathematical critical thinking skills after the use of advocacy learning with open-ended problems based on students' mathematical skill that had been categorized into three groups, namely high, medium, and lower groups in the experimental group. The N-Gain calculation results in the experimental group based on the high, medium, and low groups can be seen in Table 4.

Table 4. N-Gain at mathematical critical thinking skill based on prior knowledge skills

Group of prior knowledge Skill	N	N-Gain (%)	
		Mean	Stand. Dev.
High	8	69.84	23.87
Medium	22	44.20	20.41
Low	6	37.63	13.52

Based on Table 4, the N-Gain mean of mathematical critical thinking skill of the three groups is relatively different. This can be seen from the average of mathematical critical thinking skills of students with mathematical skills, in general, considered to be in high, medium, and low categories, respectively 69.84, 44.20, and 37.63. From the average results, it can be concluded that the high group has an average of N-gain which is relatively higher than the other two groups. However, to see whether or not the improvement in critical thinking skills of high group students' needs to be further tested using the one-way ANOVA test.

One-way ANOVA calculation results of mathematical critical thinking skills between prior knowledge skill for high, medium, and low obtained F of 5.75 with a significant coefficient of 0.007. These results indicate that there are differences in the improvement of mathematical critical thinking skills between high level, medium level, and low level group students in advocacy learning with open-ended problems. In other words, the improvement of students' mathematical critical thinking skills between the high level, medium level, and low level in advocacy learning with open-ended problems is not the same. Therefore, N-Gain data analysis on mathematical critical thinking skills continued with the Turkey test.

Based on the Tukey test (Figure 1), in the N-Gain mathematical critical thinking skill, there is a significant difference between the high-level and the other two groups in the experimental group. Meanwhile, in N-Gain mathematical critical thinking skills, there is no significant difference between the medium and lower groups.

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Tukey 95% simultaneous confidence intervals
Individual confidence level = 98.04%
High subtracted from
              Lower      Center     Upper       — —┤— — — — —┤— — — — ┼ — — — +— ·
Medium       -46.24     -25.64     -5.04                  (-----------*-----------)
Low          -59.16     -32.20     -5.25           (------------*-----------)

                                                    — —┤— — — — —┤— — — — ┼ — — — +— ·
                                                      -50        -25        0        25

Medium subtracted from
              Lower      Center     Upper       — —┤— — — — —┤— — — — ┼ — — — +— ·
Low          -29.55     -6.57      16.42                          (------------*------------)
                                              □     — —┤— — — — —┤— — — — ┼ — — — +— ·
                                                      -50        -25        0        25
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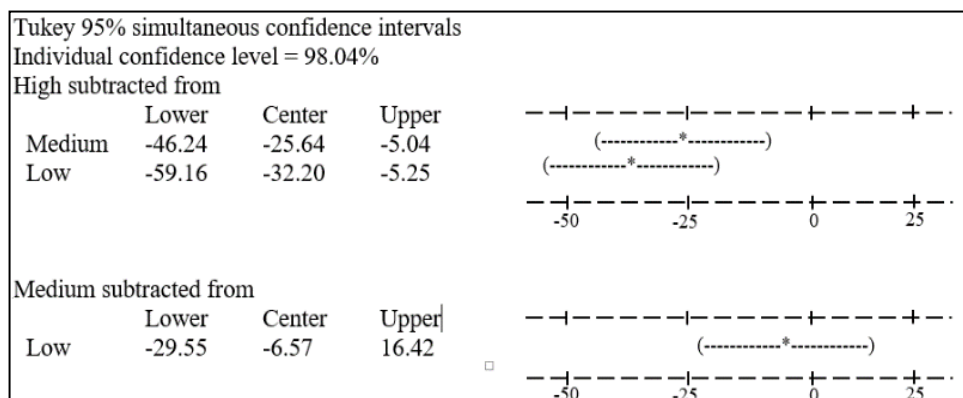
Figure 1. Tukey test N-Gain

An advocacy is a learning approach usually done for lesson with social themes. With this learning, students are allowed to discuss social issues through a debate process. Similarly, in learning mathematics with an advocacy, learning more often uses the debate method. Mathematics learning which is usually carried out using discussion and question and answer is less optimal. Thus, it needs to design a learning activity in a mathematics class to be more enthusiastic. The ability of students' critical thinking becomes better by becoming a motivator for certain opinions related to the topic being studied, requiring students to focus on the topic predetermined and considered important. The topic for debate is an issue that matches the interests and needs of students. This causes the students' mathematical argumentation skills to be better. This advocacy learning requires students to learn to be responsible for the opinions they will convey, both individual and group. In advocacy, students are trained to be able to discuss well with their groups in solving the problems given before expressing opinions that will be conveyed. Since it trains students to work together, they do not rely on one person in the group who is considered capable, but rather all of them participate actively in the learning process (Alexander, Manuain, Silla, & Dami, 2020; Haryanto & Suhartono, 2019).

Advocacy learning with open-ended problems leads students to answer problems in many ways, allowing many correct answers. With this condition, students' intellectual potential and experience in the process of finding new ideas can be explored. Besides, this learning provides opportunities for students to dig up information, discuss the results of solving problems that have been obtained in their group, and try various ways to solve problems. With open-ended questions, students' critical thinking skills can emerge when they are in a critical state where the problem must be solved and requires unusual solutions. For example, when a student is required to generate ideas to solve a mathematical problem, from his observations and explorations and linking the situation he is facing with his mathematical knowledge, he must also be critical in choosing strategies and controlling them, and think what he should do to solve the problem at hand. In this case, the metacognitive process must be empowered, namely

monitoring, controlling, and making the right decisions. Students must have the courage to take risks and be responsible for their choices or decisions. Students are also required to learn not to hesitate to make decisions.

Hence, students in the experimental group (the class using advocacy learning with open-ended problems) are accustomed to estimating, testing the observed pattern rules, and then continuing to formulate them. This is in line with the results of previous research, which states that an advocacy learning with open problems can improve students' ability to solve mathematical problems because students are used to identifying issues at hand and discussing what plans can be used to solve the problems (Nurhasanah & Julyanti, 2019). By identifying the problems faced and discussing the plans used to solve the problem, students indirectly carry out critical thinking activities such as solving a problem with a specific goal, analyzing and organizing ideas based on existing information (Cahyono, 2015; Haryani, 2011; Redhana, 2013).

Students in the control class have inadequate opportunities as experienced by students in the experimental class. This is due to the characteristics of learning in the control class where learning is still dominated by teachers. A teacher becomes a learning center or learning resource for students. The teacher takes a significant role in transferring knowledge to students. The teacher explains the lesson learned. Otherwise, students will calmly listen to the explanation given by the teacher. The question and answer process only go one way. After a series of lessons explained, the teacher provides several exercises about what has been learned without being modified. Students are not accustomed to solving mathematical problems but are accustomed to question of mathematics.

Furthermore, it was found that the average of the posttest score for students' critical thinking skills in the experimental group (a class taught using advocacy learning with open-ended problems) is 21.49 (see Table 3). This result indicates that the students' ability to think critically in mathematics learning in the experimental class is optimal. Meanwhile, the pre-test score of students' critical thinking skills in the experimental group (a class with an advocacy learning approach using open questions) is 8.99. This is most likely due to students who are not used to learning through an advocacy learning with open-ended problem. Students are accustomed to learning conventionally or in a way that teachers have commonly used. Students need learning adaptations when facing with new learning situations. There is advocacy learning in this new learning situation by providing open-ended problems. Besides, the authors also suspect that the pre-test results are not optimal because the portion of difficult questions in the set test still dominates the tests made by researchers. With the majority of students unable to solve the questions, the open-ended question category given during the pre-test was categorized

as very difficult for students. This is following the results of interviews conducted with students and daily journal entries for learning, which state that the mathematics questions are more difficult compared to the questions that teachers usually give in conventional learning.

The open-ended problem's characteristics include the availability of a learning environment that must be adapted to students to develop and express their mathematical understanding and allow various correct solutions. The students can respond to problems in their way. They are also involved in activities and learning. Students can use mathematical knowledge and skills comprehensively with many different solutions. Students can choose their favorite strategy to answer problems, and this allows the teacher to discuss with students the strategies they use to solve the problems. Students can give reasons to other students for their solution. These characteristics are emphasized during mathematics learning using an advocacy so that the experimental group students become accustomed to facing open-ended problems (Douglas et al., 2012; Kurniawan et al., 2018).

The study findings are in line with previous research, which states that the advocacy learning provides a better impact on critical thinking skills compared to conventional learning (Sinaga, 2013). Also, advocacy learning requires students to be directly involved and participate in the process of defending arguments so that theoretically, they can improve critical thinking skills, increase responsibility and activity in the classroom. The activeness in advocacy learning can be realized by proposing ways of solving math problems given by the teacher through the debate process (Tandililing, 2013). Students are required to be advocates to present certain opinions related to the topic being studied (Lisnawati, 2020). Students must use all their abilities such as research skills, analytical skills, and reading skills to participate in advocacy learning so that learning becomes more active in debate in a mathematics classroom. By actively involving students in the debate process, it is expected that students' critical mathematical abilities in mathematics will continue to be properly trained.

Moreover, the results of the N-Gain analysis show that there is an increase in students' mathematical critical thinking ability (see Table 4). Besides that, the experimental group students perform better than the control class in mathematical critical thinking skills. These results indicate that, in general, students in mathematics learning using advocacy learning with open-ended problems can analyze the arguments of statements or conclusions given. Students have knowledge of, at least, relevant and correct mathematical concepts so that mathematically the students are strong in learning mathematics. Furthermore, students can show the relationship between their understandings of the problems with the conclusions obtained after solving the problem.

Open-ended problems provide an opportunity for students to investigate various strategies and ways that they believe suitable for their ability to elaborate on problems. The aim is that students' mathematical thinking skills can develop optimally. At the same time, the creative activities of each student are communicated through the teaching and learning process. Open-ended problems allow students to think more deeply. Thinking critically and deeply is part of higher-order thinking with different answers so that students with low abilities can respond to problems in meaningful ways. In theory, the advantage of open-ended problems is that students participate more actively in the learning process and express their ideas more frequently, and allowing students to use wider opportunities to use their mathematical knowledge and skills as a whole. Students with low abilities cannot respond to problems in meaningful ways independently. Routine questions given by teachers in conventional classrooms cause students to be less active and their critical thinking skills are not good.

The difference in the increase in critical thinking skills between the three groups of students in the experimental class can be attributed to students' initial skills. This is because the initial ability significantly affects the process of learning mathematics in the classroom (Yang & Wu, 2012). The initial ability of a student is an ability that a student possesses before he follows the lesson (Purnami, Widodo, & Prahmana, 2018). The initial ability (entry behavior) describes the students' readiness in receiving lessons to be delivered by the teacher. Students' initial abilities in this study can be described as mathematical skills of students before participating in learning. This skill is essential for the teacher to know before starting the learning because the teacher can use it to understand: (a) whether students already have prerequisite knowledge for learning; and (b) the extent to which students already know the lesson that will be presented (Razak, 2018). As revealed by previous research, which states that in general, there is a strong relationship between students' initial ability to their skills to think mathematics critically (Haeruman, Rahayu, & Ambarwati, 2017).

Learning mathematics with an advocacy learning by providing open-ended problems has helped them develop and demonstrate mathematical critical thinking skills. The students' activeness in the high-level group can be seen from the learning activities. As stated by Tandililing (2013) and Lisnawati (2020), advocacy learning can be realized in proposing ways of solving math problems given by the teacher through the debate process. The debate process is an activity of arguing between two or more students, either individually or in groups. Students are trained to present arguments and defend those using logical and justified reasons. This condition shows that students are actively giving reasons that make sense so that their arguments can be accepted, and think critically to counter the arguments presented by other students. Debates that are directed at learning mathematics make students more active in

thinking by analyzing real problems around them to create a deep impression in mathematics learning. Debates that are directed at learning mathematics make students more active in thinking by analyzing real problems around them to create a deep impression in mathematics learning.

Based on the results of the study, the increase in critical thinking skills of students with high initial abilities is better than that of the other two groups, namely the low and medium initial ability groups. Therefore, this research implies that the advocacy learning can be used as an alternative to learning mathematics for students with high prior knowledge.

Conclusion

The results of this study conclude that the ability to think critically in students treated with an advocacy leaning by giving open questions in mathematics learning is better than students who are given conventional learning. With the increase in mathematical critical thinking skills, students whose prior knowledge in the high-level group did better than students with low and moderate prior knowledge. Mathematics teachers are advised to use an advocacy leaning as an alternative in teaching mathematics to improve students' critical thinking skills. The study results were only carried out on the topic of set and only focused on critical thinking skills and prior knowledge so that other researchers are encouraged to carry out similar research by considering the diversity of teaching materials and students' abilities.

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