Increasing Student Mathematical Critical Thinking Ability Through the Development of Geometry Instructional Device Based on Van Hiele's Theory

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Abstract. Objective of this study is to increase students' critical thinking skills through geometry instructional device based on Van Hiele's theory. Instructional devices developed include lesson plans and student worksheet based on Van Hiele's theory. The stages of instructional are integrated with the stages of learning Van Hiele's theory which consists of five stages, namely information, direction orientation, explication, free orientation, and integration. The development model used is adapted from the Plomp model which consists of three phases, namely the initial investigation phase, the prototype development phase, and the assessment phase. The subjects of this study were grade VIII students of SMP 13 Padang. The results of the research obtained showed an increase in indicators of mathematical critical thinking abilities of students using geometry instructional devices based on Van Hiele's theory.

1. Introduction

The ability to think critically is one potential that must be developed in students. This ability is needed for students to solve problems in mathematics specifically the topic of geometry. According to Duron, et.al [1] critical thinkers are capable of analyzing and evaluating information, raising vital questions and problems, compiling those questions and problems clearly, gathering and assessing relevant information using abstract ideas, being open-minded, and communicating them with effective. By having the ability to think critically mathematically, students can solve mathematical problems and find the right solution [2]. Therefore the ability to think critically mathematically is something that students must have in order to solve problems, especially in the topic of geometry. In fact, students have not optimally had the ability to think critically mathematically as seen from the results of assessments in various schools.

An assessment conducted at several schools in Padang City, namely in SMPN 30 and SMPN 13 Padang, found that the learning process in schools had not yet optimized the development of students' mathematical critical thinking skills. Students are still accustomed to non-routine problems that require the ability to think critically in solving mathematical problems. Based on preliminary findings from the score of mathematical critical thinking ability of junior high school students found the score according to the indicator of mathematical critical thinking ability as follows (Table 1).
Table 1. Distribution of Mathematical Critical Thinking Ability Test Scores for Students

| No | Indicators | Number of students | Average of Scale | Percentage of Scale |
|----|------------|--------------------|------------------|---------------------|
|    |            | Scale 0 | Scale 1 | Scale 2 | Scale 3 | Scale 0 | Scale 1 | Scale 2 | Scale 3 | Scale 0 | Scale 1 | Scale 2 | Scale 3 | Scale 0 | Scale 1 | Scale 2 | Scale 3 | Scale 0 | Scale 1 | Scale 2 | Scale 3 |
| 1  | Identify   | 4       | 15      | 10      | 17      | 1.87    | 62.32   | 1.54    | 51.45   | 1.72    | 57.25   | 1.74    | 57.97   | 1.54    | 51.45   | 1.72    | 57.25   |
|    | Connection | 15      | 5       | 12      | 14      | 1.54    | 51.45   | 1.74    | 57.97   | 1.54    | 51.45   | 1.74    | 57.97   | 1.54    | 51.45   | 1.74    | 57.97   |
| 2  | Identify   | 2       | 19      | 15      | 10      | 1.72    | 57.25   | 1.72    | 57.25   | 1.54    | 51.45   | 1.74    | 57.97   | 1.54    | 51.45   | 1.74    | 57.97   |
|    | Connection | 12      | 8       | 15      | 11      | 1.54    | 51.45   | 1.74    | 57.97   | 1.54    | 51.45   | 1.74    | 57.97   | 1.54    | 51.45   | 1.74    | 57.97   |

In Table 1 it can be seen that students' mathematical critical thinking skills are still relatively low. The average scale obtained by students is less than 2. Then when viewed from a percentage of the scale, it is at a magnitude of 57% which is still below the passing grade value of 80. Based on interviews with several students they admit that the difficulty of understanding the geometry occurs because it is difficult to think abstract shapes, analyze the properties of the observed geometry objects, and present geometry objects in the form of figure. This is due to the fact that students have not been able to identify, connect and evaluate any information given in geometry problems. In addition, students also feel less interested in learning mathematics. To improve students' mathematical critical thinking skills, geometrical learning based on Van Hiele's theory is used [3].

There are five stages of Van Hiele's theory that support the learning process including information, direction orientation, explication, free orientation, and integration [4]. The stages in this theory are not only characterized by qualitatively different levels of thinking, but also by different internal knowledge and its processing [5]. The development of Van Hiele theory based geometry learning device is one of the efforts to fulfill learning devices in schools. This learning device is expected to be able to train the geometrical thinking process of students to be actively involved in learning and to develop one of the abilities needed in the 21st century, namely critical thinking skills. This is also supported by research conducted [6] with the results of research showing an increase in critical and creative thinking skills in Van Hiele theory-based learning. The aim of this study is to improve students' mathematical critical thinking skills through the development of valid, practical and effective geometry learning tools based on Van Hiele theory.

2. Method

This type of research is development research. The development model used to develop the Van Hiele theory-based geometry learning device was adapted from the Plomp model which consists of three stages, namely the initial investigation stage, the stage of developing or making a prototype, and the assessment stage [7]. Activities carried out at the initial investigation stage are needs analysis, identification and study of the mathematics curriculum, analysis of learners' conditions and concept analysis. Activities carried out at the development or prototype stage are designing learning tools through various one to one and small group assessments. The assessment phase is carried out when the field test is carried out, namely in a class or large group to find out the extent of practicality and effectiveness of the mathematics learning tools developed in the implementation of learning.

Research data were collected through validation sheets, teacher and student response questionnaire sheets, observation sheets for the implementation of lesson plans, interview sheets, and the results of tests of students' mathematical critical thinking skills. The subjects of this study were students of SMPN 13 Padang.

3. Results and Discussion

3.1. Results of the Preliminary Investigation Phase
This initial investigation was carried out for two days. (1) The first day was held on January 21, 2019 by observing learning in the classroom and conducting interviews with teachers of Padang 13 Junior High School; (2) the second day was held on January 23, 2019 by observing learning activities and conducting interviews with students of SMPN 13 Padang.

Based on observations of learning activities conducted at SMPN 13 Padang, students can see what is explained by the teacher on the board. But when asking questions and answers with the teacher, only a few students responded. Some students seem confused with the material explained. During the learning process there are still many students who have difficulty in identifying problems, connecting mathematical concepts with each other and difficulty in drawing conclusions. In addition, data was also collected through interviews.

The results of the interviews obtained from three students of class VIII SMPN 13 Padang that is (1) high-ability students claim to like learning mathematics but sometimes difficulty understanding material related to geometry, (2) capable students are claiming to like mathematics if it is memorization but difficulty in analyzing the questions, (3) low-ability students do not like mathematics because there are still many basic mathematical concepts that have not been mastered.

Based on the results of the interview obtained information that students do not like mathematics in the field of geometry. This is because students are still at the stage of thinking concretely, so they need props to facilitate the development of students' thinking stages. Interviews were also conducted to the teacher to determine the state of students related to learning geometry.

The results of interviews conducted with mathematics teachers at SMPN 13 Padang, information was obtained that there were still many students who were less interested in learning mathematics, especially in the field of geometry. Difficulties experienced by students is to identify existing problems and determine the relationship of objects with one another. With the presentation of the results of the initial investigation it is understood that there needs to be an improvement in the learning tools used by the teacher. Improvements were made namely at the learning stage by paying attention to the diverse stages of thinking of students and provided props that support to attract students' interest in learning the mathematics of geometry.

From the results of the needs analysis that has been done, so that the learning process that involves active learners is to provide worksheets that are able to encourage students to actively participate in learning geometry and design learning activities in the classroom in the form of lesson plans. Learning devices that are designed can train and assist students in understanding geometry material. In addition students are expected to have an interest in learning geometry so as to improve students' mathematical critical thinking skills.

3.1.1. Curriculum Analysis Results
At this stage a review of the curriculum used at SMP Negeri 13 Padang, 2013 curriculum. Based on the results of the curriculum analysis, there were no changes or additions to the core competencies because they covered all aspects, namely aspects of divinity, social, cognitive, affective, and psychomotor as a whole general. Changes were made to the indicators of competency achievement adjusted to indicators of mathematical critical thinking ability.

3.1.2. Concept Analysis Results.
Concept analysis aims to determine the mathematical material fields of geometry needed in the development of geometry learning tools to achieve indicators of competency achievement. The material learned in class VIII of SMP in the even semester of 2018/2019 is Pythagorean, Circle, Tangent Circle, Plane 3-dimensional space, Statistics and Opportunities. In this study only focused on material related to geometry so that Statistics and Opportunities material was not subjected to concept analysis.

3.1.3. Student Analysis Results.
The results of the analysis of students were identified, the first was that students were less motivated to learn geometry. This is because students find it difficult to imagine something abstract. Secondly,
students recognize that in learning geometry they often forget formulas. This is a sign that students do not understand the basic concepts of what is learned and have not gone through appropriate learning experiences. Third, students do not feel the benefit of learning geometry in everyday life. One reason is the problems presented in learning are not close to the lives of students. Fourth, students prefer to talk with their friends. When the teacher explains there are some students who are not focused on the teacher's explanation. Fifth, students prefer groups. This is marked when working on the exercises students do it in groups. This behavior signifies that open personal learners and not individualism. Sixth, students are sometimes less able to work on problems that are not similar to the example problems that contain indicators of mathematical critical thinking ability.

Based on an analysis of students, learning tools are designed that help overcome the problems that occur. One learning tool that can help students in learning geometry is Van Hiele theory based learning which is equipped with Van Hiele theory based worksheets

3.2. Results of the Prototype Development Phase
After the learning indicators are formulated, the next step is to design geometry learning tools. Some principles in the preparation of learning plans are based on the Minister of Education and Culture Regulation [8], while the development of worksheets refers to the principles of learning according to the Ministry of National Education [9]. The following description of the prototype characteristics in the form of a learning plan and geometry worksheets based on Van Hiele's theory.

3.2.1. Characteristics of learning plans and worksheets based on Van Hiele’s.
Components that are characteristic of Van Hiele's theory-based learning plans are contained in the steps of the activities that are designed to facilitate the different levels of thinking of students. Characteristics of the worksheet based on Van Hiele theory that are designed contain about the activities of students in achieving indicators of competency achievement. It also trains students' level of thinking as well as mathematical critical thinking skills. Following are excerpts from Van Hiele's theory-based learning plans and worksheets

![Figure 1. Footage of the presentation of the learning plan based on Van Hiele's Theory](image1.png)

![Figure 2. Footage of the presentation of the worksheet based on Van Hiele's Theory](image2.png)

3.2.2. Results of Validation of Geometry learning tools based on Van Hiele Theory
The learning device that has been designed in the initial stages is called prototype I. This device is first validated through self-evaluation, after it is revised, then a discussion with experts (expert review) is validated.

3.2.3. Self-evaluation Result
The aspects evaluated in the Van Hiele theory-based geometry learning plan are the same as those on the worksheet. The results of the self-evaluation have been corrected for typing errors, repetition of sentences, errors in numbering order, and clarity in the picture.

3.2.4. Expert Review Result
The learning device was validated by 5 lecturers including 3 mathematics education experts, 1 education technology expert, and 1 language expert.

| Table 2. The Validation Results of the Geometry Learning Plan Based on Van Hiele Theory by Experts |
|---|---|---|
| No | Validation Aspect | Validity Index | Category |
| 1 | Component aspects of the learning plan | 83,12% | Very Valid |
| 2 | Aspects of Learning Activities | 85,00 % | Very Valid |
| 3 | Language Aspects | 80,00% | Valid |
| | Total Average | 82,70% | Very Valid |

| Table 3. Results of Geometry Worksheet Validation by Experts |
|---|---|---|
| No | Validation Aspect | Validity Index | Category |
| 1 | Presentation | 82,22 % | Very Valid |
| 2 | Content Feasibility | 84,16 % | Very Valid |
| 3 | Language | 83,33 % | Very Valid |
| 4 | Graphic / Appearance | 75,00 % | Valid |
| | Average Validity Index | 81,17 % | Very Valid |

Based on Tables 2 and 3 above, the geometry learning tool based on Van Hiele's theory already fulfilled valid criteria. However, there are still more improvements made based on the advice of the validator.

3.2.5. Practicality Results Geometry learning tools based on Van Hiele Theory
The revised results of prototype I are called prototype II. Prototype II has been declared valid by experts then tested the practicality of the geometry learning device.

3.2.6. One To One Evaluation Result
One to one evaluations were carried out on three students of class VIII.5 SMPN 13 Padang. Based on observations made during the individual evaluation activities it was concluded that the worksheet based on the Van Hiele theory could be used well even though there was a slight improvement. This is consistent with the study of theory that a device is said to be practical if it can be used and understood easily by its users.

3.2.7. Small Group Evaluation Result
A small group evaluation of the worksheets was conducted for six students in class VIII.5 of SMPN 13 Padang. The results of the evaluation are as in Table 4.
Table 4. Results of Analysis of Observation Sheet on the Use of Geometry Learning Devices Based on Van Hiele Theory

| No | Aspects                        | Observer Rating Score | R   | P(%) | Category |
|----|--------------------------------|-----------------------|-----|------|----------|
|    |                                | (Meeting)             | 1   | 2    | 3        | 4    | 5    | 6    |        |          |
| 1  | Introduction                   | 3,4 3,6 3,4 3,8 3,6 3,4 3,53 | 88,33 | VP   |
|    | Main activity:                 |                       |     |      |          |      |      |      |        |          |
|    | Step I. Information            | 3,0 3,4 3,6 3,2 3,2 3,2 3,26 | 81,67 | P     |
| 2  | Step II. Direction Orientation | 3,3 3,6 3,6 3,3 3,6 3,3 3,45 | 86,25 | VP   |
|    | Step III. Explication          | 3,0 3,3 4,0 3,7 3,3 3,7 3,50 | 87,50 | VP   |
|    | Step IV. Free Orientation      | 3,5 3,5 4,0 4,0 4,0 4,0 3,83 | 95,83 | VP   |
| 3  | Step V. Integration            | 3,0 3,0 3,5 3,0 3,0 3,0 3,08 | 77,08 | P     |
|    | Closing                        | 3,5 3,8 3,8 3,8 3,8 3,8 3,75 | 93,75 | VP   |

Note: VP = Very Practical  
P = Practical

Table 5. Results of Questionnaire Responses of Students to Worksheets Based on Van Hiele Theory on Small Group Evaluation

| Aspect                    | Percentage of Practicality (%) | Category     |
|---------------------------|--------------------------------|--------------|
| Presentation              | 85,00                          | Very Practical |
| Ease of Use               | 81,54                          | Practical    |
| Legibility                | 89,58                          | Very Practical |
| Time Allocation           | 87,50                          | Very Practical |
| Average                   | 85,90                          | Very Practical |

Based on Table 4 and Table 5, it is known that Van Hiele's theory based learning tools for each aspect of the assessment meet practical criteria. However, there are still more aspects that need to be improved based on observations made during the small group evaluation activities.

3.3. Assessment Phase Result

The assessment phase is carried out by testing the Prototype 4 learning tool on grade VIII.8 students of SMPN 13 Padang. The test is carried out to review the practicality and effectiveness of Prototype 4. The aspect of practicality is assessed based on teachers and students' response. The effectiveness that observed in this learning is the mathematical critical thinking ability of students. The aspects that assessed is the presentation, usage, legibility, and time. The results of students' responses for the worksheet are more than 77,61%, and teachers’ responses are more that 75%. So that, the learning tools is practical.

The effectiveness of the use of Van Hiele theory based geometry learning tools is intended to see the extent to which these learning devices can help achieve the objectives of learning geometry. An increase in students' mathematical critical thinking skills seen from the quiz scores of each meeting and the results of tests of mathematical critical thinking skills.
Based on Figure 3, it can be seen that the average value obtained by students at each meeting has increased, but at the fifth meeting the average has decreased. This is not so problematic because the acquisition value is still relatively high when compared to the value of the first meeting and the second meeting. In addition, based on the results of tests of students' mathematical critical thinking skills obtained that 22 people out of 30 people who completed. This shows that there are as many as 73.33% of students already have a score above the specified KKM (Minimum Achievement Criteria) that is 80. While the average value of students' critical thinking skills tests is 82.5. This shows the learning device has met the effective criteria in increasing students' mathematical critical thinking skills.

The stages in Van Hiele learning which are quite important in practicing mathematical critical thinking skills are the stages of free orientation. This is because at this stage students are trained with questions that contain indicators of critical thinking skills. With the habituation done by students' critical thinking skills tend to increase with each meeting. The results of this study are also supported by research [10] - [14] with the results of the study that the implementation of activities based on Van Hiele phases of geometry learning has a positive impact on the development of higher levels of geometric thinking as well as a means to develop higher level thinking skills in geometry. One of the higher order thinking abilities is critical thinking ability. According to [15] also shows the results of research which states that learning that involves students actively in project-based or collaborative activities can encourage the development of students' critical thinking. In addition, according to [16] the results of the study state that critical thinking skills enable students to be accustomed to facing challenges and solving problems by analyzing their own thinking to make choices and draw conclusions, so that qualified graduates are able to compete with the challenges of the ASEAN Economic Community (AEC).

4. Conclusion
Based on the results of research conducted, it was found that the learning tool based on Van Hiele theory that was developed fulfilled valid, practical and effective criteria in improving the mathematical thinking ability of students of SMPN 13 Padang.

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