Instructional media for space geometry based on augmented reality to improve students’ spatial reasoning

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Abstract. Technology development is growing rapidly in the 21st century. It takes a thorough preparation in various fields to deal with this condition, including in education field. Technology can be used to help learning process in the classroom particularly as an instructional media. This research aims to determine the effectiveness of instructional media of space geometry based on augmented reality in improving students' spatial reasoning. The data were collected in one junior high schools in Yogyakarta-Indonesia. Thirty-three students of grade 8th were involved in this study. The results show that learning media is feasible to use and effective to improve students' spatial reasoning as shown from the spatial test in which most of the students can solve the spatial reasoning tests and the spatial score were increase from 49 to 79.35 from the maximum score 100. This finding implies that AR instructional media could enhance spatial skill as it provides better visualization.

Keyword : mathematics learning media, augmented reality, spatial reasoning

1. Introduction
Mathematics is a science learned at every level of schooling. However, mathematics is considered to be a difficult subject not only notice elementary students, but students at all levels, including junior high students. As a results, mathematical skills of the Indonesian students are still low and need to be improved. The results of international test support this claim. Trends in International Mathematics and Science Studies (TIMSS) 2011, Indonesia received an average of 386 points in mathematics [1]. These results are still far below the OECD average, which is around 493.

In addition to the TIMSS data, mathematics becomes a difficult subject which is also evidenced by the existence of the National Education Standards Agency report [2] about the results of the 2016-2018 junior high school mathematics National Exam which is still in the low category for national scale. From the results of the 2016-2018 Junior High School Mathematics National Exam is known that the absorption of mathematical material which becomes National Examination material according to BNOSP [2] is still relatively low, especially in geometry and measurement material. Geometry and measurement are the most difficult material based on National Examination results. In other words, there is a need to evaluate and improve the learning process in order to improve students' understanding of geometry.

The surface area and volume of the flat side space are one of the topics students must learn on geometry material. On this topic, students learn about spatial/three-dimensional perspectives. The one of the purposes of learning surface area and volume of flat side objects is students can practice the ability
of spatial reasoning. However, this materials are usually delivered by teachers giving formulas directly to students. Therefore, the objectives of this learning are not yet accomplish.

On the other hand, reasearchers of the previous studies claimed that spatial reasoning is an important skills that student must obtain, because they are: (1) has a correlation with geometry and can be used to construct understanding of geometry; (2) problem solving; (3) predict abilities and achievements in mathematics; (4) success relates to science, technology, architecture and cartography; (5) predict career. The importance of spatial reasoning is declared by Guzel & Sener [3]. Based on the explanation, it shows that spatial reasoning is one of the abilities that must be possessed by students. In reality, the learning of geometry in SMP Negeri 1 Piyungan still does not facilitate the improvement of students' spatial reasoning. The learning carried out is still focused on solving mathematical problems.

Based on preliminary research that has been conducted, it was found that students still had difficulty in learning mathematics when using an existing reference book. The reference book used by students is still only focused on giving formulas and practice questions.

Students difficulties in learning are caused by many factors such as internal and external factors. One of the internal factor is student interest in learning mathematics, while factors from outside students one of them is the lack of use of learning media that can help the learning process. Learning media is a tool used to help and facilitate learning. In its development, learning media can be developed by utilizing technological developments. One of them is a smartphone-based learning media. This smartphone-based learning media is considered relevant because currently most of junior high school students have smartphone and familiar with it. As an evidence, data from the Ministry of Communication and Information [4] shows that 53.6% of 189.5 million Indonesians who have mobile phones are junior high school students.

Learning media development by utilizing smartphones has many ways, one of them is by using augmented reality technology. Augmented reality is a technology that combines two-dimensional or three-dimensional virtual objects into a real environment and then projects the virtual objects in real-time [5]. This virtual object serves to display information that cannot be directly accepted by humans. At present, the use of augmented reality in the development of instructional media is not widely used. It is because there are many people who are unfamiliar with augmented reality technology. In addition, augmented reality is also included in new technology in Indonesia. This is one of the reasons why augmented reality technology has not widely used yet in the development of instructional media.

In fact, in the development of Augmented reality using principles, such as augmented reality is emerging of real and virtual environments, running in real-time, and integration between objects in three dimensions [6] where these three principles can facilitate the delivery of information to students if used in learning media development. The use of augmented reality technology on smartphones as a learning media can make learning more attractive to students. Besides being able to attract students' interest, the use of this technology also makes students more able to explore their knowledge, especially in the topic of geometry.

The use of AR-based learning media in understanding spatial geometry material is needed because it has been proven in several previous studies that show that this learning media is very effective. As conducted by Suharso [7], it was produced that 85% of teachers thought that the application of 3D space building props could improve students' understanding of the mathematics material of 3D building material. From this explanation, it can be seen that AR based geometry space learning media is effectively assist students in understanding space geometry material. According to Chen [8] AR is able to motivate students with intuitive functions and user-friendly interactions, which can increase understanding in the teaching and learning process. In addition, according to Pangestu et al [9] instructional media for space geometry based on augmented reality can facilitate the development of students' reasoning abilities in general. This study try to examine the effectiveness of the AR instructional media in developing students' spatial reasoning.
2. Research Methods

The purpose of this research is to create mathematics learning media based on Augmented Reality, and to know the quality of learning media from the aspect of effectiveness in terms of the spatial reasoning of junior high school students. This research was conducted in January-April 2019 at one of Junior High School in Yogyakarta. It involving 31 students using Android-based smartphones.

Data analysis techniques were carried out to determine the categories of learning media that were developed based on effective quality criteria. In this study, students are given 5 multiple choice test items to test students' spatial reasoning abilities. The example of the item test can be seen in Figure 1 dan Figure 2.

![Figure 1. Example questions to test the ability of spatial reasoning on the spatial perception aspect](image1)

![Figure 2. Example questions to test the ability of spatial reasoning on the spatial visualization aspect](image2)

Students’ responses on the test were then checked whether their answers correct or wrong. The percentage of students' spatial reasoning of each aspect is calculated based on the following formula.

\[ t = \frac{\sum N_t}{\sum N} \times 100\% \]

- \( t \) : percentage of students’ spatial reasoning (%)
- \( \sum N_t \) : Number of students who answer correctly
- \( \sum N \) : Number of students taking the test
3. Research Results and Discussion

3.1. Research Result

Students’ spatial reasoning is measured after the students learn space geometry topics using AR instructional media in addition to textbook and worksheet. During the lessons, students were asked to explore the worksheet that has been enhanced with AR technology.

Data of students’ spatial reasoning were collected using test consisting of 5 multiple choice questions. Each question represents each indicator of spatial reasoning, namely spatial orientation, spatial visualization, mental rotation, spatial relations, and spatial perception. Spatial orientation ability is the ability where students are able to think and determine a shape. Spatial visualization ability is the ability where students are able to know changes in the shape or position of an object. Mental rotation ability is the ability where students are able to know the changes in flat shape or space build based on the direction of rotation. Spatial relations ability is the ability where students are able to know the shape of a room or relationship between parts of the building. While the ability of spatial perception is the ability where students are able to know the parts of a flat shape or build space in a vertical or horizontal position.

Table 1 Table of Student Spatial Reasoning Test Result

| No | Remarks                          | Spatial Reasoning Test Result |
|----|---------------------------------|------------------------------|
| 1. | Number of student               | 31                           |
| 2. | Maximal Score                   | 100                          |
| 3. | Minimal Score                   | 0                            |
| 4. | Highest score achieved by student | 100                        |
| 5. | Lowest score achieved by student | 40                          |
| 6. | Average                         | 79.35                        |
| 7. | Standard Deviation              | 16.72                        |

Table 1 shows the results of students’ spatial reasoning tests which show that there are students who get the maximum score. This indicates that the student is able in all aspects of spatial reasoning. Nevertheless, there are still students who score 40, in other words only able to in two aspects of spatial reasoning ability from the five aspects tested. In general, the average score for all aspects of spatial reasoning are 79.35. This score increased in comparison with the initial score of students’ spatial reasoning which was 49. When analyzed for each indicator, the following table is generated.
Table 2 Percentage of Student who completed Spatial Reasoning Test Result for Each Indicator

| No | Indicator          | Student who answer correctly |
|----|--------------------|------------------------------|
| 1. | Spatial Orientation| 17                           | 55%                          |
| 2. | Mental Rotation    | 29                           | 94%                          |
| 3. | Spatial Relation   | 22                           | 71%                          |
| 4. | Spatial Visualization| 31                         | 100%                         |
| 5. | Spatial Perception | 24                           | 77%                          |

Table 2 illustrates that all participants can answered spatial visualization problem correctly. This followed by mental rotation and spatial perception. Meanwhile, the spatial orientation aspect seems to be to themost difficult aspect to solve by the students, which is only about 55% of students who can answer correctly.

3.2. Discussion
The average score of spatial reasoning after the students use AR media is increase from 49 to 79.35. This implies that augmented reality-based learning media are effective to improve students' spatial reasoning abilities. This result echoed studies conducted by Phon et al, [11], and Bell et al [12], which have proven that AR instructional media enhance spatial ability. AR provides real 3D models that could improve visualization skill which is an essential skill in spatial reasoning skill.

Based on the Table 2, when viewed from each indicator of spatial reasoning, it can be seen that AR-based learning media helps students especially in the ability of spatial visualization and mental rotation where each gets a percentage of 100% and 94%. This is in accordance with the opinion of Pangestu [9], which states that the media of learning geometry based on augmented reality space can facilitate the development of students' reasoning abilities, especially on spatial visualization abilities. This findings support the data of previous research studies that found AR technology contribute to improve spatial visualization [13]–[15]. AR technology allows students to manipulate a virtual object freely from many angles or perspectives. In this study, students can move around the marker, move the marker back and forward to explore and see the objects from various perspectives. The student can see cube and cuboid from the front, rear, above, under, or other sides. This could help students in understanding the material and task given during the learning process such as determining cube nets and area of the cube surface.

In addition, the ability of spatial relations, students who answered correctly about 71%. Whereas in the ability of spatial perception, students who answered correctly around 77%. This is still in the good category. Spatial relations ability is the ability where students are able to know the shape of a room or relationship between parts of the building. While the ability of spatial perception is the ability where students are able to know the parts of a flat shape or build space in a vertical or horizontal position. This might due to the instructional media that has been developed in this study did not expose these two aspects. The media was only for volumes, nets and areas of cube and cuboid thus it did not provide features that allows students to manipulate parts of the objects (in this study cube and cuboid).

Due to deficiencies in the learning media used in this study, however, the AR media could not maximize students' abilities regarding spatial orientation. This is evidenced by the percentage of students who answered correctly only 55%. Spatial orientation ability is the ability where students are able to think and determine a shape and in this study, the AR media the shapes were already determined before, this did not allow students to manipulate and determine new shapes.

In general, AR instructional media contribute to students’ spatial skills and improve students engagements during the lesson. AR could help students emember and retain the knowledge that is learnt [16].
4. Conclusion
Based on the results of research and discussion about the development of media learning space geometry particularly flat-side based on augmented reality to improve students' spatial reasoning ability at junior high school level. AR give opportunity for students to explore the geometrical objects in three dimensional and from different angles. However, there is several issues need to be considered when using AR based instructional media such as lighting conditions in the room, students' ability to use AR-based learning media, and the readiness of teachers to use AR-based learning media.

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