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THE POTENTIAL OF MOBILE AUGMENTED REALITY AS A DIDACTIC AND PEDAGOGICAL SOURCE IN LEARNING GEOMETRY 3D

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Abstract

The COVID-19 pandemic in Indonesia requires teachers and students to perform learning activities online. Meanwhile, teachers use a variety of technology products in the classroom without paying attention to the didactic, pedagogical, and content aspects. This is due to time constraints and short learning adjustments that should be flexible to this pandemic. Therefore, this research provides an alternative by exploring the potential of augmented reality as a didactic and pedagogical source in learning geometry. An exploratory case study design was used to reveal this potential, while three mathematics teachers and twenty-six students from three schools in Indramayu Regency, Indonesia, participated in the research. Data from observations and documentation were checked, extracted, entered verbatim, and coded. The results of the interview data were analyzed using the content analysis method, while those from the geometry understanding test and student response questionnaires used descriptive analysis. Consequently, the research results showed that augmented reality was useful as an alternative didactic and pedagogical source of learning geometry during the COVID-19 pandemic. This conclusion was based on the reason, first characteristically augmented reality technology can be integrated with textbooks or certain learning methods. Second, the results of the geometry understanding test showed that there were more students who answered the questions correctly than the students who answered incorrectly. Third, the results of questionnaires and interviews showed that students had a positive attitude during the geometry learning process. Therefore, the researcher believes that the use of augmented reality is worthy of being an alternative didactic and pedagogical source and has the potential to be applied to other subjects both during the COVID-19 pandemic and after the COVID-19 pandemic.

Keywords **–** Augmented reality, COVID-19 pandemic, Didactic and pedagogical sources, Learning geometry.

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1. Introduction

The COVID-19 pandemic forced the closure of schools and caused changes in the interaction processes involved during teaching and learning in Indonesia, as well as other countries (Bubb & Jones, 2020; König, Jäger-biela, Glutsch & Jäger-Biela, 2020; Sepulveda-Escobar & Morrison, 2020). Although some countries have begun to reopen learning activities with strict health protocols, such as the implementation of social and physical distancing, the prediction of the ending of this pandemic is still completely unknown (König et al., 2020). This uncertainty has encouraged school principals to mobilize teachers to lecture online (Bubb & Jones, 2020). Hence, teachers strive to integrate technology into the learning process or at least to communicate to support related activities (Adedoyin & Soykan, 2020).

However, the lack of preparation time and the absence of training provided by schools has caused many teachers to adopt certain technologies for online learning without paying attention to didactic, pedagogical, and material content aspects. The term didactic refers to the teacher's efforts to create learning resources that allow interaction between students and the material content (Kansanen, 1999). Conversely, the term pedagogy refers to the teacher's efforts to make instructional designs that allow interaction with students while learning certain materials (Kansanen, 1999).

In Indonesia, the Ministry of Education and Culture recommends technology products that can be used as alternative learning sources for students and teachers during the COVID-19 pandemic (Almanthari, Maulina & Bruce, 2020). These alternatives include e-learning platforms, such as "Rumah Belajar" and "SPAD," alongside online learning applications, like MejaKita, ICANDO, Ganeca Digital, Smart Class, Quipper School, Teacher Room, Your School, Zenius, Cisco Webex, and Pahamify (Almanthari et al., 2020). However, neither resources from e-learning platforms nor online applications focus on geometric material contents that are accessible by teachers or students as a didactic or pedagogical source.

Several technology products can be used as didactic and pedagogical sources in mathematics classes, especially geometry, such as mathematics analysis software (MAS) (Pierce, Stacey & Wander, 2010), geometry, and algebra (GeoGebra) (Zulnaidi, Oktavika & Hidayat, 2020). Other products include Cabri 3D (Kariadinata, Yaniawati, Juariah, Sugilar & Muthmainah, 2019; Taylor, Koklu & Topcu, 2013), Windows Geometry (Wingeom) (Fonna & Mursalim, 2018), and Matrix Laboratory (Matlab) (Chauvon, Saucez & Wouwer, 2019). Also, some software packages, such as Dr. Geo, Geonext, MathGV, and Poly (Elias & Figueira-Sampaio, 2015), are useful for this purpose. Specifically, these programs, which are very familiar and can be used as a reference for studying 2D and 3D geometry (Elias & Figueira-Sampaio, 2015), will be more effective if used directly in classrooms. The condition of schools during the COVID-19 pandemic prevented the use of these programs in classrooms because the teaching and learning process was being performed remotely. Also, a study was conducted on the condition of the mathematics teaching process in junior high schools in Indramayu Regency, Indonesia. The preliminary observations of this study showed that most teachers relied on textbooks and WhatsApp groups as a didactic and pedagogical source and also gave instructions to students to learn from these books. Subsequently, the teacher and students conducted a discussion process through the WhatsApp group by providing explanations via voice notes available in the application menu.

Understanding the concept of geometry requires didactic and pedagogical sources that facilitate representation (Parzysz, 1991; Pittalis & Christou, 2013) and visualization (Battista, 1990; Ben-Haim, Lappan & Houang, 1985; Gerson, Sorby, Wysocki & Baartmans, 2001). These sources should also promote reasoning (Clement & Battista, 1992; Pittalis & Christou, 2010). However, the mathematics textbooks used in the classroom are not sufficiently facilitated (Fernández-Enríquez & Delgado-Martín, 2020). Although the use of WhatsApp can motivate, encourage, and allow students and teachers to share information about the mathematics subject (Jere, Jona & Lukose, 2019), it cannot facilitate the process of representation, visualization, and reasoning, which are the basis of students' geometric thinking constructs.

A technology that can be used for representation and visualization, alongside as a geometrical, didactic, and pedagogical source in mobiles, is Augmented Reality (AR) (Fernandez-Enriquez & Delgado-Martín, 2020). Many studies have designed and developed several mobile augmented reality applications to facilitate students to learn geometry. For instance, İbili, Çat, Resnyansky, Şahin and Billinghurst (2019) developed the AR Geometry Tutorial System (ARGTS) to improve 3D geometric thinking skills. Also, Omar, Ali, Mokhtar, Zaid, Jambari and Ibrahim (2019) developed Mobile Augmented Reality (MAR) to improve the visualization skills of students learning orthographic projection. De Ravé, Jiménez-Hornero, Ariza-Villaverde and Taguas-Ruiz (2016) designed DiedricAR to help study geometry, while Cahyono, Sukestiyarno, Asikin, Miftahudin, Ahsan and Ludwig (2020) created a mobile math trails program to help students learn mathematical modeling. Furthermore, Rohendi, Septian and Sutarno (2018) designed a mobile augmented reality app to help students learn 3D geometric shapes.

These previous study results confirm that the use of mobile augmented reality facilitates the teaching and learning process of geometry. However, there are still few that design and develop augmented reality integrated with geometry textbooks and learning instructions. The didactic source in this research is a textbook, while the pedagogical source is the instructions for learning geometry, and both are equipped with AR. The textbook with AR is designed to help students improve representation and visualization, while the instructions for learning geometry with AR help the teacher-student interaction process. Based on these explanations, this research aims to explore the potential of mobile augmented reality as a didactic and pedagogical source as seen from the implementation design, student responses, and geometry understanding.

2. Research Method

2.1. Research Design

An exploratory case study design was used to analyze the potential of mobile augmented reality as a didactic and pedagogical source. This potential was shown from the implementation design, student responses, and understanding of geometry after learning during the COVID-19 epidemic. The case study design was used as it enabled the investigation of a particular event, situation, or condition and provided information about how the event or process occurred (Swanborn, 2010). Delello (2014) explained that the case study design related to the application of technology in learning was the best way to reveal how technology was integrated into the classroom. Meanwhile, Yin (2017) stated that an exploratory case study was useful for situations where there were no clear set of results for the intervention being evaluated.

For the implementation process, this research identified schools that had properly effected the online learning process. Also, negotiations were performed with several junior high school principals as the target of this study, and three schools were willing to implement the use of textbook with AR and mobile augmented reality. This implementation in learning geometry was performed in class VIII in the odd semester during the COVID-19 pandemic. After obtaining permission from the principal, several grade VIII math teachers were contacted, and they agreed to perform the textbook with AR and mobile augmented reality in their math class. Subsequently, one class from each of these schools was chosen by purposive sampling, which was based on student activeness in participating in learning in other subjects online. Lastly, it was agreed that the textbook with AR and mobile augmented reality was to be implemented on the solid shapes, such as prisms, cuboid, cubes, and pyramids in the odd semesters.

According to the Learning Implementation Plan (LIP) in the school curriculum, the research was performed for six meetings, where five were for the learning process, and one was for evaluation. The distribution of material at each meeting is presented in Table 1.

Meeting	Material
1st	Identifying the elements and properties of prisms, rectangular, and cubes
2nd	Identifying and constructing nets of prisms, rectangular, and cubes
3rd	Determining the surface area of the prism, rectangular, and the cube
4th	Determining the volume of the prism, rectangular, and the cube
5th	Comparing volumes based on properties
6th	Evaluation

Table 1. Distribution of Material

2.2. Participants

This research involved three grade VIII mathematics teachers from different schools in Indramayu Regency, Indonesia. They were all female within an age range of 26 - 33 years, classified as young teachers, and possessed good technological literacy. Meanwhile, 26 persons were selected from the 79 students in the three schools that were willing to participate voluntarily. School A had eight students, B had ten, while C also had eight, while the characteristics were nine males and seventeen female, as presented in Table 2.

No	School	Total	Grade	Gender	Age
1.	School A	8	VIII	3 male students, 5 female students	13-15 years
2.	School B	10	VIII	4 males, 6 females	14- 15 years
3.	School C	8	VIII	2 males, 6 females	14-15 years

Table 2. Student Characteristics

Before starting the research, the 26 students were invited to zoom meetings to obtain explanations and discussions about the technical implementation of learning geometry using textbook with augmented reality and mobile augmented reality. Then, two students were selected from each school to be trained on operating the textbook with augmented reality and mobile augmented reality correctly via purposive sampling, as they were the most active in discussing and asking questions during the meeting. Subsequently, the teacher instructed these students to teach other members of their school.

Previously, 26 students and their parents had requested permission by signing consent forms to participate in the research. This was to clarify and ensure that there were no misunderstandings between all the parties involved, and so, students without consent were not forced to participate actively.

2.3. Data Collection Tool

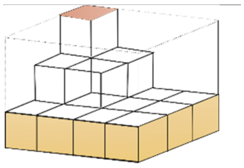
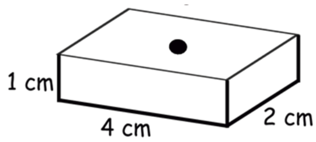
The data collection in this study used observational guidelines, 3D geometry understanding tests and interview guidelines. In this study, observation aims to determine the level of student activity in using augmented reality mobile applications. The observation tool used is an observation sheet on student activities during learning which consists of four indicators, namely: (1) student readiness in learning; (2) student activities in using augmented reality mobile applications; (3) student activities in discussion; (4) student activities in working on practice questions. The aspects assessed can be seen in Table 3.

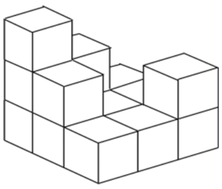
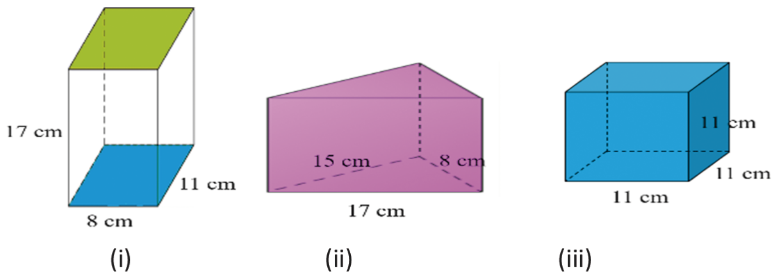
Indicator	Assessment Aspect
Student Readiness	1. Students have installed an augmented reality mobile application. 2. Students have prepared a mobile augmented reality integrated textbook.
Student Activities During Learning	1. Students pay attention to instructions from the teacher. 2. Students are able to operate augmented reality mobile applications well. 3. Students are able to follow the instructions contained in the integrated textbook of the augmented reality mobile application. 4. Students pay close attention to the AR animation that appears in the cellphone camera.
Student Activities in Discussion	1. Students are able to communicate the results of their observations well. 2. Students are able to ask questions about material that is not understood.
Activities in Doing Exercises	1. Students use AR applications to help understand questions. 2. Students are able to construct problems. 3. Students are able to visualize the problem in the form of pictures.

Table 3. Indicators and Aspects of Student Activities during Learning

In addition to observations, researchers also used tests to measure students' understanding of 3D geometry material, which consisted of four indicators: (1) identifying the elements and properties of 3D geometry; (2) constructing 3D geometry webs, and (3) determining the edge structure of 3D geometry;

(4) compare volumes of 3D geometries based on their properties. Each indicator is represented by each test item. The geometric understanding test instrument can be seen in Table 4.

<table>
<tr><th>Description of task</th><th>Example</th></tr>
<tr><td>Identifying the elements and properties of 3D geometry</td><td>
Find the number of unit cubes with unpainted sides!</td></tr>
<tr><td>Constructing 3D geometry nets</td><td>If the size and sign of the block are known.


Make at least three different nets for the cubiod.</td></tr>
<tr><td>Determining the structure of the 3D geometry</td><td>Take a look at the 3D geometry image below!

Suppose the stack of unit cubes above represents a multi-story building, and one plot (cube) has four rooms with the same shape and size.
a) How many floors are the building?
b) How many rooms are on each level?
c) How many rooms are there in the building?</td></tr>
<tr><td>Comparing 3D geometry volumes by their properties</td><td>

Which image has the greater volume?</td></tr>
</table>

Table 4. Description of Test

Furthermore, the researchers also conducted interviews with students aimed at identifying student responses using an augmented reality mobile application. The type of interview used is a semi-structured interview. There are 15 questions asked to students. These questions, for example "Do you have difficulty using mobile augmented reality?", "Can AR animations displayed in augmented reality mobile applications help you understand 3D geometry material?", "Are the instructions given in AR integrated textbooks? make you have difficulty in understanding 3D geometry material?".

2.4. Data Analysis

Data from observations, geometry comprehension tests and interviews were analyzed qualitatively. Observational data were checked, calculated and categorized as active level. Furthermore, the data obtained from the results of the geometric understanding ability test were analyzed using descriptive statistical analysis (maximum, minimum, average and variance values). In this study, descriptive statistical analysis aims to provide a general description of student achievement in completing the geometry comprehension test. In addition, the researcher also calculated the percentage of each indicator based on the answers (true and false).

Furthermore, the data obtained from the interviews were transcribed, presented in the form of a matrix or summary table, and analyzed using the content analysis method. In this study, there were five stages in conducting content analysis, namely: (1) reading and formulating the transcript of the interview; (2) build categories; (3) coding the interview text; (4) analyze the results; (5) presenting the results of the interview. The process can be seen in Figure 1.

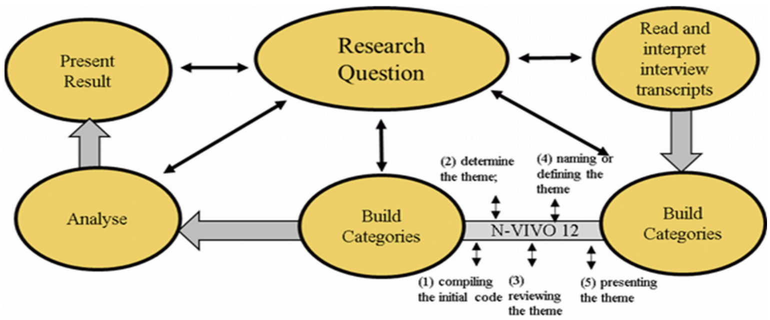


Figure 1. Data Analysis Flow

In this study the process of building categories and coding using the N-VIVO 12 application, with the following steps: (1) compiling the initial code; (2) determine the theme; (3) reviewing the theme; (4) naming or defining the theme, and (5) presenting the theme. In the research, the themes identified from the interviews were (1) student difficulties; (2) happy students; (3) helping students. The identified themes are presented, interpreted and concluded based on the research formulation.

2.5. Mobile Augmented Reality Design

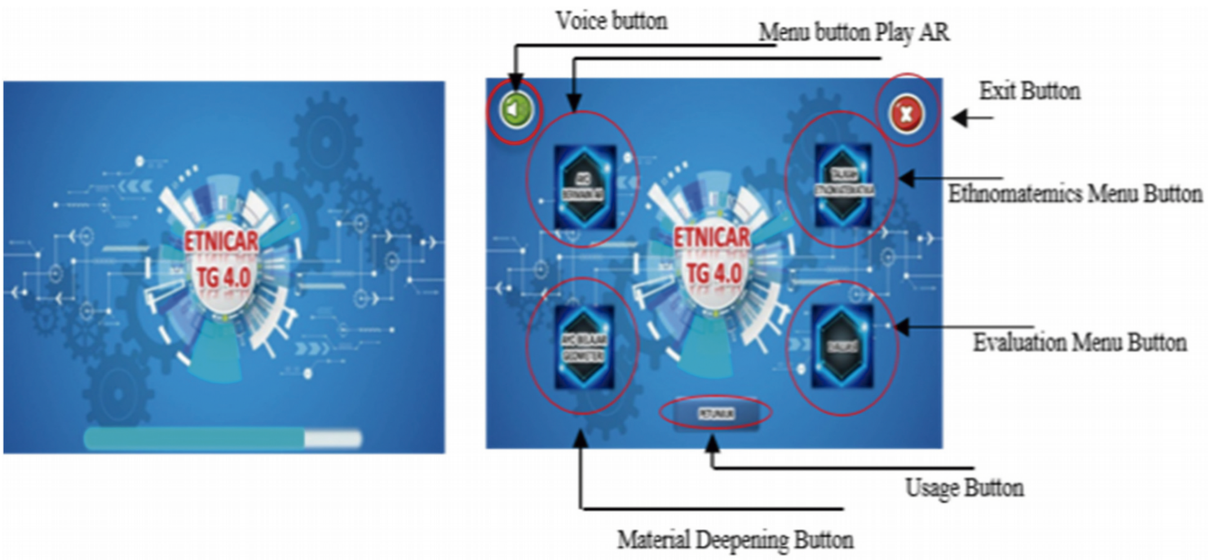


Figure 2. Menu and Display of Mobile Augmented Reality

The mobile augmented reality design in this research, as seen in Figure 2, was called “ETNICAR TG 4.0” and was presented with four menus. These menus were “Let’s Play AR”, the “Ethnomathematics”, the “Let’s Learn Geometry”, and “Evaluation”. The “Let’s Play AR” menu allowed students to point the camera at the textbook with AR, while the “Let’s Learn Geometry” menu enabled the selection of videos containing geometric material to facilitate deeper learning. Conversely, the "Evaluation" menu contained question exercises for the students to attempt. Meanwhile, there were seven (7) geometric concepts that were facilitated, including the prism, cuboid, cube, pyramid, sylinder, cone, and sphere.

The process of using mobile augmented reality began with the selection of material to be studied by the students, where some pictures in the textbooks represented geometric objects as AR markers (see Figure 3). Afterward, the teacher asked the students to point their cameras at the already indicated AR marker, which displayed object representations and geometric concepts. The students were able to explore the concept of geometry from the explanations in the video on the "Let's Learn Geometry" menu. Then, an exercise was given on the "Evaluation" menu to assess the students' understanding.

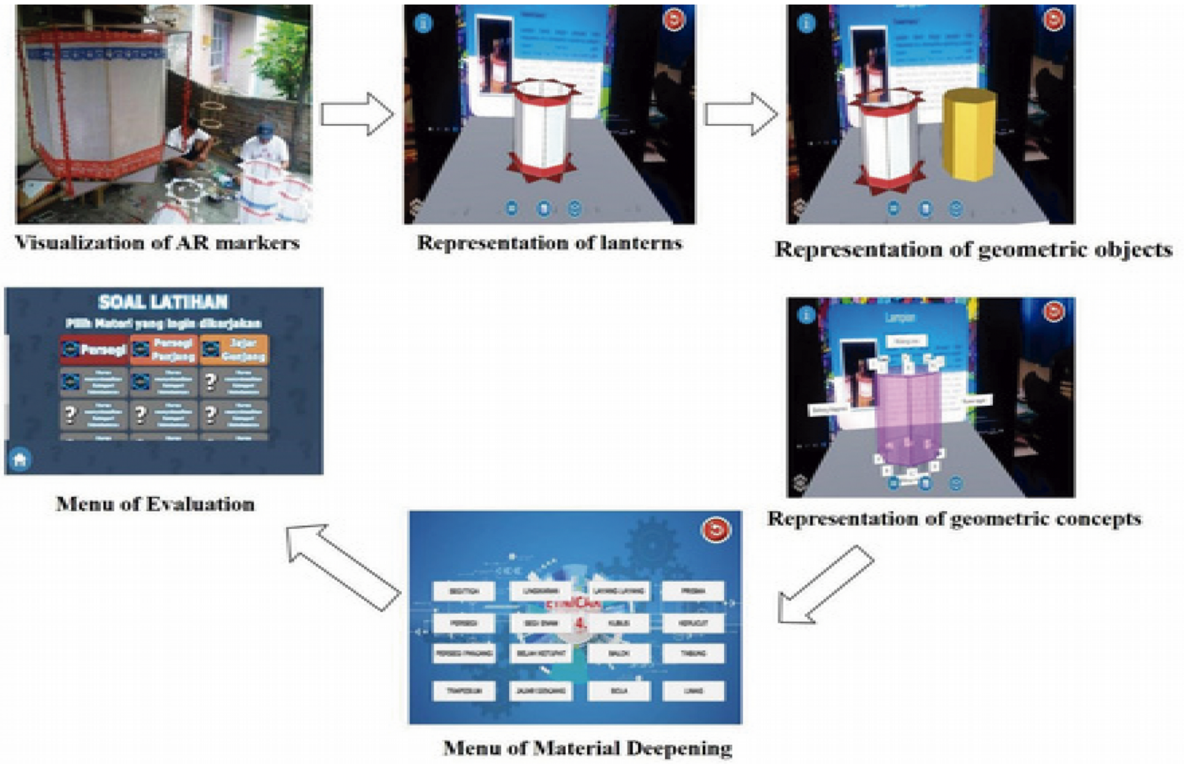


Figure 3. The Process of Using Mobile Augmented Reality

3. Results and Discussion

3.1. A Textbook with AR As a Didactic Source

The front pages of the textbook with AR consist of the cover, author's identity, preface, as well as the basic competencies, and related standards, table of contents, concept map, introduction, and the related material. The cover of the textbook with AR was attributed with a header that integrated AR technology in learning geometry and aimed to distinguish between ordinary textbooks and those with AR. Also, it consisted of many marker objects that used local wisdom pictures and was named "GeoARkeology: Building 3D geometry concepts through cultural heritage."

It contained seven (7) materials, consisting of cuboids, cubes, prisms, pyramids, sylinders, cones, and spheres. Each material was divided into five indicators, which were definitions, elements, and properties, as well as nets, surface area, and volume, while each part was equipped with a description and an image as an AR marker.

Representative views for the contents of the textbook with AR are seen in Figures 4. The first page explains the prism and is represented by pictures of people making lantern lamps, which are a form of local wisdom in a geometric representation of a hexagon prism. Students that had installed the

"ETNICAR TG 4.0" application were able to point their cellphone cameras at the marker. Then, an animation, which is a representation of 3D and geometric objects appeared, and this illustration helped the students visualize geometric objects as if they were real.

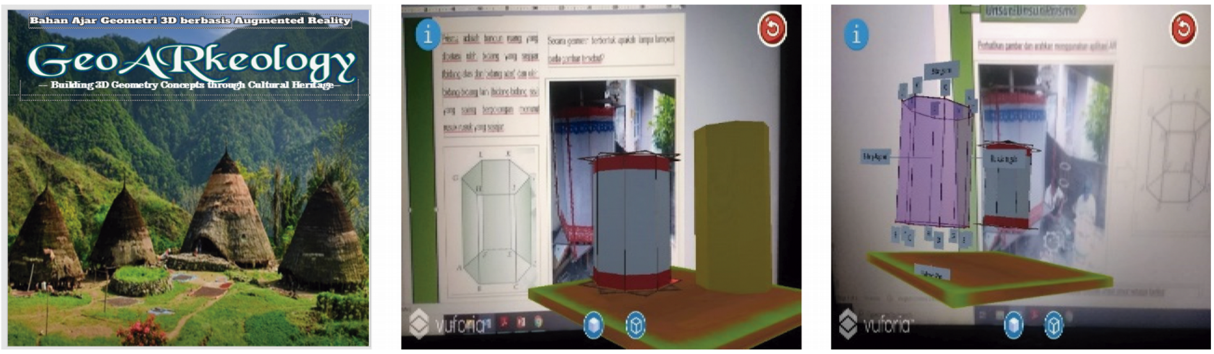


Figure 4. AR Textbook View

3.2. Mobile Augmented Reality As a Pedagogical Source

The pedagogic process of the mobile augmented reality during the COVID-19 pandemic was instructional, meaning that the instructional process performed by the teacher was based on the menu contained in AR. In practice, this instructional process was classified into three stages:

3.2.1. Early Stage

By implementing health protocols during the COVID-19 epidemic, three students from each class were invited by the teacher to be taught using mobile augmented reality. They were trained on the installation process, how to use the menu, and the textbook with AR, while the teacher prepared a training schedule for these students, as presented in Table 5.

No	School	Day	Time	Training Materials
1	School A	Monday	09.00 – 10.30	Installation Process
2	School B	Tuesday	10.30 – 12.00	Introduction to the Application Menu
3	School C	Wednesday	13.30 – 15.00	Use of Textbooks with AR and other materials

Table 5. AR Training Schedule

The training process occurred for three days, starting at 09.00 am until 03.00 pm, and the students in each group obtained information on the use of mobile augmented reality. The observation of the training process by the teacher generally went smoothly. In the beginning, when the mobile augmented reality was explained, the students seemed silent, paid attention, and appeared to be confused from the looks on their faces. However, when the teachers began to demonstrate how the technology worked, they began to understand it.

3.2.2. Core Stage

In this stage, the teacher asked two members from each class to create a study group in one of the students' homes. The appointed students were responsible for the members of their respective groups, and each was to report the progress and obstacles encountered during the learning process, which was performed for seven meetings. Each group as seen in Figure 5, had their ways of implementing the teacher's instructions, as some studied outside the home, while others were in the village or even the school library.

Figure 5. Learning Implementation

At the beginning of the lesson, in the next process, the teacher gave instructions to each group to open the "Let's Learn Geometry" menu and the "Textbook with AR." This textbook with AR contained geometry materials, and the students chose the content they wished to learn. Then, they opened the "Let's Play AR" menu by pointing the camera at the textbook on the marker image. On the "Let's Learn Geometry" menu, they were able to access geometry materials through explanations formulated as instructional videos, which required the students in each group to have internet data packages to enable them to connect and open learning videos. However, some students did not have internet packages, which resulted in the inability to open the material, an issue that was solved by the provision of data by the teacher. Subsequently, each student was instructed to try their hand at using mobile augmented reality to provide a direct experience for the students. Also, it improved the representation of geometric objects, as well as the visualization of the elements and the geometric properties.

At the first meeting, problems were encountered when the students started using the mobile augmented reality, such as the refusal of animations of the 3D geometric object representations to appear on cameras that were damaged or too dark. To solve this issue, the students borrowed their friends' cellphones to use the application at the subsequent meeting, which resulted in conducive learning. The students were enthusiastic about studying the net, surface area, and the volume of the prisms, cuboids, and cubes in the textbooks with AR. Hence, they recorded and summarized all the important material. At each meeting, the teacher instructed all the students individually to work on the practice questions about the nets, surface area, and volume of these shapes on the "Evaluation" menu in mobile augmented reality. Apart from studying in groups, the teacher also kept track of the student learning process at home by giving individual assignments listed on this menu at each meeting. At the last meeting, each group was instructed to make a video presentation on the summary of the material from the first to the last meeting to assess the internalization and memorization of geometric concepts by the students. The videos that were sent by each group were evaluated, and the teacher made notes from them.

3.2.3. Closing Stage

At the final meeting, each student was given an individual test sent by the teacher, which contained four questions that were to be solved in 60 minutes. When finished, the students were required to send their photographed answers to the teacher's email. The test aimed to measure the understanding of geometric concepts after the learning process.

3.3. Potential in Fostering Student Understanding of Geometry and Learning Attitudes

The first test item investigated the students' ability to identify the elements and properties of 3D geometry, while the second was related to recognizing and constructing. For these tests, the students were asked to construct nets from cuboids with different markings on each side. Meanwhile, the third item analyzed the ability to determine the number of 3D geometric shapes and asked the students to determine the number of levels, the room in each, and the whole room. Finally, the fourth item tested the students' ability to compare volumes of 3D geometry by compiling understanding items at each school. Table 5 shows the results of the descriptive analysis of these tests.

School	N	Maximum Score	Minimum Score	Average	Variant
School A	8	85	48	65.1	157.84
School B	10	88	51	70.2	152.84
School C	8	85	54	66.5	97.43
Total	26	88	48	67.5	131.54

Table 6. Student's Geometry Understanding Test Results

Item Indicator	Proportion of Correct Answers		Proportion of Wrong Answers	
	Total	**(%)**	**Total**	**(%)**
Identifying the elements and properties of 3D geometry	16	62	10	38
Constructing 3D geometry nets	12	46	14	54
Determining the structure of the 3D geometry	14	54	12	46
Comparing 3D geometry volumes by their properties	11	42	15	58
Average		51		49

Table 7. The Proportion of Student Answers

The above results showed that the average score of 26 students was 67.5. Also, the average of school B, at 70.2, was greater than schools A and C, at 65.1 and 66.5, respectively, and the maximum score, which was 88, was likewise greater than these two schools. This showed descriptively that there was no significant difference between the three classes and their geometric understanding was relatively the same. The analysis of the answers of 26 students based on the item indicators is shown in Table 7.

Table 6 shows that in question one, 16 students, at 62%, correctly identified the elements and properties of 3D geometry, while the remaining 10 students, which amounted to 38%, were unable. In question two, 12 students were able to determine the nets of the cuboids, while the remaining 14 were not, and both comprised 46% and 54%. Furthermore, 14 students, at 54%, were able to determine the structure of 3D geometry in question three, while the remaining 12, at 46%, were unable. Finally, in question four, 11 students were able to compare the volumes of 3D geometry, while the remaining 15 were unable, and both groups made up 42% and 58%, respectively.

There are three types of difficulties experienced by students in completing geometry tests, namely obstacles of ontogenic, didactical, and epistemological origins. Brousseau (2002) defined an obstacle of ontogenic origin as a difficulty caused by a mismatch between the learning provided and the level of students' cognitive development. Meanwhile, the didactical obstacle is defined as the difficulty of the method, approach, media used, or the instructions given by the teacher (Brousseau, 2002). Furthermore, the obstacle of epistemological origin refers to difficulties caused by limited contexts known by students (Brousseau, 2002).

The epistemological obstacle occurred when the students had difficulty visually representing the field of the unit cube, which is not visible to the eye, alongside its rib structure located on the inside of a large cube. Furthermore, the students experienced difficulties arranging the parts of the block plane perfectly into nets, while others had problems seeing the 3D geometric shapes from various points of view to the net's construction. Students also misinterpreted the set of unit cubes presented in 2D objects and assumed that each level has the same number of cubes when determining the 3D form, causing them to multiply by 3. Meanwhile, some had difficulties calculating multiplication correctly when comparing volumes from 3D shapes.

Conversely, the obstacles of ontogenic origin concern the type of learning style and prior knowledge of students. The style can be seen from the students' involvement during the learning process, which caused them to be uncomfortable and have low enthusiasm in following the steps while using a textbook with AR and mobile augmented reality applications. Their initial knowledge level also affected their absorption in learning geometric concepts, as students with low initial knowledge tend to have difficulty completing assignments from the teacher. Therefore, the type of learning style and the understanding level affected the geometry comprehension test results.

The students also experienced the didactical obstacles caused by incorrectly receiving the instructions from the teacher, which happened when the use of textbooks with AR and augmented reality mobile applications was explained. Also, some students ignored the teacher's instructions when completing the assignments and exercises in the AR textbooks. In addition, several students experienced problems at the time of implementation while operating augmented reality mobile applications due to the specifications of their mobile phones.

Although there are still many obstacles in using augmented reality mobile applications, based on data from interview transcript analysis, it is clear that students think augmented reality mobile applications can help students understand geometry material. This can be seen from the results of an interview with one of the students, as in the following quote:

G: Have you ever studied geometry using augmented reality technology?

S: I have never studied geometry using augmented reality technology.

G: Do you enjoy learning using textbooks with AR and mobile augmented reality applications?

S: It turns out that learning geometry using augmented reality technology is very fun, exciting, and not boring because it is not only used at school but also in the home.

G: Are you excited to follow all the directions from the teacher while studying using textbooks with AR and mobile augmented reality applications?

S: Even though it was confusing at the beginning, I was able to follow all the teacher's directions in using augmented reality technology well at the next meeting.

G: Does the use of textbooks with AR and mobile augmented reality applications help you learn 3D geometry concepts?

S: The display of 3D geometry objects, 3D animations, and geometry learning videos found in textbooks with AR and augmented reality mobile applications are very helpful in understanding geometry concepts.

The results of the interview illustrate that most students feel enthusiastic about following the teacher's instructions. Most students also find the use of textbooks with AR and mobile augmented reality applications fun and not boring. In addition, based on interview data analysis, it was stated that the use of mobile augmented reality applications can help students understand geometry material because it provides several useful features and animations for students. Students stated that with augmented reality mobile applications, they could help them visualize 3D geometric objects well. In interviews conducted with students, they stated that previous geometry lessons only used geometry textbooks that presented 3D shapes in the form of 2D images; However, with the use of integrated geometry textbooks, augmented reality mobile applications can help students represent and visualize 3D geometric objects directly. Therefore, the use of augmented reality mobile applications makes students more motivated in learning. In addition, some other students stated that after starting to use mobile augmented reality, they did not study geometry at home.

3.4. Discussion

AR technology characteristically combines digital information and physical objects simultaneously and identifies real objects accurately via a tablet or smartphone to create a new reality (Azuma, 1997). This new reality provides information, knowledge, alongside an experience of abstract entities and is difficult to understand and observe (Bower, Howe, McCredie, Robinson & Grover, 2014). Therefore, users construct understandings or mathematical concepts in solving problems directly (Dunleavy & Dede, 2014). In this research, AR technology was designed to be used as a didactic and pedagogic resource in geometry learning.

The AR was technology integrated with school geometry textbooks because it requires real objects formulated as two-dimensional images. These images are then used as markers to build a new reality in the form of three-dimensional animated objects. The textbook with AR was also designed to allow students to interact directly by observing geometric objects and communicate their understanding in writing. Consequently, the understanding gained from students' interaction through this textbook with AR makes the technology a potential didactic resource.

Meanwhile, the potential of AR as a didactic resource in geometry learning is conceptually linked to other international studies. Fernandez-Enriquez and Delgado-Martín (2020) developed an AR application as a didactic resource to teach polyhedra and help prospective junior secondary education teachers to visualize and understand three-dimensional geometry. Cheng (2017) created AR-integrated textbooks and concluded that students felt less cognitive load, stronger motivation, and more positive attitudes toward the experience while reading these materials. Also, Aveleyra, Racero and Toba (2018) designed an AR application and discovered that the application has the potential to be used didactically in physics classes.

Therefore, AR can also be used as a pedagogical resource. In this research, the application was integrated with instructional-based learning. The teacher instructed the students to use the applications to facilitate independent learning inside and outside the classroom. In addition, the AR application was designed to help teachers explain and explore 3D geometry concepts with the material menu and evaluation function. Therefore, mobile augmented reality has potential as a pedagogical resource.

The study as a pedagogical resource is supported by another international research. Sampaio and Almeida (2016) identified and explored AR-assisted pedagogical strategies by evaluating aspects of the competencies developed and the level of student motivation. Bitter and Corral (2014) concluded that AR has proven effective in the pedagogical process for various school lessons. In addition, Kerawalla, Luckin and Woolard (2006) suggested four design requirements should be considered in adopting AR into pedagogy, namely flexible content, guided exploration, limited time, and paying attention to institutional and curricular needs (Kerawalla et al., 2006).

Meanwhile, the use of textbooks with AR and mobile augmented reality as didactic and pedagogical resources can foster the understanding of geometric concepts and student learning attitudes. Based on the test results show that the average value of 26 students is 67.5. However, the proportion of students' wrong answers was quite significant, as 38% and 54%, respectively, incorrectly identified the elements and properties of 3D geometry and determined the nets. Moreover, 46% and 58%, respectively, determined the shape structure and compared the 3D geometry wrongly. The results of the analysis found that there were three types of student difficulties in completing the geometry test, namely obstacles of ontogenic origin such as learning styles, prior knowledge; obstacles of didactical origin such as incorrectly receiving instructions, ignoring instructions, obstacles in operating textbooks with AR and mobile augmented reality; obstacle of epistemological origin such as difficulty in solving problems in different ways. However, the obstacle of epistemological origin was the most dominant, involving difficulty representing the elements and properties, constructing geometric nets, determining the arrangement of unit cubes, and comparing volumes of 3D geometry. Therefore, the discussion in this study focuses more on these aspects.

The difficulties experienced by some students in this study are supported by the results of other relevant international research. Parzysz (1988) concluded that students encounter problems in the representation process, from "seeing 3D geometric images" to "knowing the properties of geometric objects". The reason is that they tend to perceive the properties of images as those geometric objects when "seeing images" (Parzysz, 1988) and Pittalis and Christou (2013) called these difficulties coding and decoding. Furthermore, Cohen (2003) identified five types of student errors when constructing nets from 2D to 3D objects, including (1) confusion between the perspective view of the solid and its net. The remaining types were (2) joining the disc and the lateral surface along a line, (3) wrong form of the edge to be joined, (4) wrong placement of the parts, and (5) other mistakes. These errors are caused because the construction of 3D nets requires the ability to transform 3D objects into 2D nets by focusing on the component parts in both representation modes (Pittalis & Christou, 2010). It also requires the ability to manipulate the image (Cohen, 2003).

Besides, Battista and Clements (1996) explained that students were unable to coordinate the number of line segments on the beam and integrate them to build a coherent mental model. Ben-Haim et al. (1985) also researched by providing two isometric and horizontal images through the question "How many cubes are needed to build a certain rectangle?" (Ben-Haim et al., 1985). The results showed that the representation of how to draw 3D shapes caused students to experience difficulty connecting isometric images and calculating hidden cubes (Ben-Haim et al., 1985).

Several studies related to measurement concluded that misconceptions occurred when students measured the length, surface area, and volume of 3D geometry (Battista, 2004; Huang & Wu, 2019; Özerem, 2012; Tan-Sisman & Aksu, 2016). According to Özerem (2012), it was caused by background knowledge, lack of reasoning, and basic operating errors in geometric measurements. Hence, Huang and Witz (2012) suggested that the measurement of the surface area needs an understanding of the concept and formula for the area of a rectangle, the concept of multiplication operations, and strategic knowledge to solve these problems. Meanwhile, the calculation of volume requires spatial understanding (Tan-Sisman & Aksu, 2016).

Students' difficulties in identifying elements and properties of 3D geometry are related to the construction of external representations or decoding. The reason is that geometric object representations are not considered knowledge. Also, the object structures captured by the five senses are not considered physical symbols, objects, or dimensions that can be retrieved, analyzed, and processed by the students' perceptual systems (Zhang, 1997). Meanwhile, Pittalis and Christou (2010) explained that 2D images are the type of external representation mode most often used for 3D geometric objects in school textbooks. This was confirmed by Mesquita (1998) that the two shapes, 2D and 3D, have different properties, where 3D is characterized as a representation of the 2D framework. In addition, representing 3D shapes is a complex process that involves the concept of 2D objects (Mesquita, 1998), causing difficulty in identifying the elements and properties of 3D geometric objects.

The construction of 3D geometric nets is part of the internal representation of construction or coding. This refers to three factors, namely (a) coding the 3D net shape by manipulating and constructing the nets, (b) building 2D images into 3D shapes, and (c) translating one representational mode of a 3D shape into another, i.e., an orthogonal view of a 3D shape into a 2D image (Pittalis & Christou, 2010). Consequently, the students experienced difficulty constructing nets because it requires the ability to translate 3D objects and 2D nets by focusing and studying the parts of objects in both modes of representation (Pittalis & Christou, 2010). It also involves spatial ability by folding to form 3D or vice versa (Cohen, 2003). Hence, they did not understand that the transformation of 3D objects into nets is not an appropriate copy of perception, but an operation performed by manipulating mental images (Cohen, 2003). The transition from the perception of a 3D object into nets requires the activation of appropriate mental actions that coordinate the various perspectives of the object (Pittalis & Christou, 2010). Mariotii (1989) assumed that the construction of a net requires coordination between the mental representation of the object as a whole and the decomposition of its parts. Therefore, the difficulties of students in constructing the nets were identified by Cohen (2003).

Also, the students had trouble determining the arrangement of 3D geometric objects. They did not understand that the ability to "read" two-dimensional representations of 3D geometric objects was a spatial visualization skill (Ben-Haim et al., 1985) and is part of two-dimensional coding representations (Cooper, 1990). This representation combines the structure of a three-dimensional visual object with the resultant stimulus proximal to a two-dimensional image (Cooper, 1990). Furthermore, this difficulty was experienced because constructing the visualization and conceptualization of 3D objects is a complex cognitive process and requires developing the ability to decode and encode spatial information (Markopoulos, Chaseling, Petta, Lake & Boyd, 2015). In fact, there are many ways to measure students' ability to determine the arrangement of 3D geometric objects. Battista and Clements (1996) created a strategy by conceptualizing the set of cubes (1) as forming a rectangular arrangement into several layers, (2) as space but not using layers, and (3) in terms of its front view. Then, (4) using the formula $L \times W \times H$ and (5) multiplying the sum of the squares on one face by the number on the other face.

In addition, the students had difficulties in comparing the 3D geometry volumes because they need the ability to distinguish the geometric properties (Denizli & Erdoğan, 2018). The comparison of different three-dimensional objects, according to their properties, depends on a related analysis (Gutierrez, 1992). Those that used the first strategy of Battista and Clements (1996) showed an awareness of the spatial structure of 3D objects, including hidden parts (Vasilyeva, Ganley, Casey, Dulaney, Tillinger & Anderson, 2013). In contrast, students who used the third strategy revealed a lack of understanding of volume, and instead of focusing on the parts that stand out from a particular perspective, failed to integrate the different views of 3D objects (Vasilyeva et al., 2013). Conversely, those that applied the fourth strategy were unsure about possessing a conceptual understanding of volume and only used the formula as a shortcut or mechanically, without understanding the 3D arrangement structure (Vasilyeva et al., 2013). These considerations were not performed by students, causing them to encounter difficulties in comparing the 3D geometry volumes.

Based on the questionnaires, the students possessed good learning attitudes. The interview results also confirmed that they felt excited and did not get bored when using AR textbooks and augmented reality mobile applications. Meanwhile, the research findings are supported by previous studies, which concluded that the use of AR helps existing or prospective teachers to present interesting learning. Also, it assists students to connect their learning experiences with the real world and create new meanings (Rosli, Baharom, Harun, Daud, Mohd & Darus, 2010). Chen (2019) suggested that learning with mobile AR can grow students' learning motivation. Hence, they can have a more positive attitude on aspects of attention and relevance than groups of students not using AR (Chen, 2019). The technology also increases their self-confidence and satisfaction and reduces high anxiety (Chen, 2019). Therefore, the positive attitude of students when learning with AR is a source of forming self-efficacy in learning mathematics (Cai, Liu, Yang & Liang, 2019).

4. Conclusion

The results confirm that AR technology can be used characteristically as a didactic and pedagogical resource. This is because first, didactically, AR can be integrated with textbooks that allow interaction with students and influence the formation of understanding of certain concepts. Second, pedagogically, AR can be integrated with learning and the teaching of certain materials to facilitate independent learning inside and outside the classroom.

Furthermore, this research reveals that the use of textbooks with AR and mobile augmented reality can increase students' understanding of geometry and learning attitudes. It effectively helps cultivate a learning attitude as shown by the students' responses to questionnaires and interviews. Therefore, these findings support the results of other international studies, which concluded that the use of AR increases learning activity, attitudes, motivation, self-efficacy, and performance, while reducing learning anxiety (Chen, 2019; Chiang, Yang & Hwang, 2014; Cheng, 2017; Fidan & Tuncel, 2019; Hwang, Wu, Chen & Tu, 2016; Lu & Liu, 2015; Sudirman, Yaniawati, Indrawan & Melawaty, 2020).

Hence, students' difficulties are not only caused by factors from the design of textbooks with AR and mobile augmented reality. Other factors, such as the level of understanding, learning styles, prior knowledge, incorrect instruction between teachers and students, obstacles in using the textbooks and application, alongside difficulties in solving problems via different methods are also involved. Therefore, teachers and parties concerned with the development of technology-based learning need to pay attention to the cognitive, affective, technical, and readiness aspects of students' facilities and infrastructure before implementing this method. Furthermore, teachers should understand that not all learning designs can be integrated with certain technology products.

Consequently, although some students encountered difficulty solving geometry questions textbook with AR and mobile augmented reality, this method can be concluded as a feasible alternative didactic and pedagogical resource applicable to other subjects during and after the COVID-19 pandemic.

5. Suggestions

The research was performed during the COVID-19 pandemic, resulting in limited communication between the teachers and students and when interacting with both parties for this study. Limitations in controlling the learning process were also a problem, as the teacher could not control the students tightly when they studied at home. Also, the research occurred in several secondary schools in Indonesia, which have limited supporting facilities and infrastructure for implementing AR technology. Consequently, the condition of the internet network and cellphone specifications owned by students were separate obstacles. Therefore, these research results can be maximized for schools with good facilities and infrastructure but will not be very different for schools with the same conditions. The characteristics of AR technology also have the potential for further research on other mathematical content. Hence, designing more attractive content is necessary for the use of AR technology as an alternative didactic and pedagogical resource for other subjects during and after the COVID-19 pandemic.

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