ISSN 2355-4185(p), 2548-8546(e)
DOI: 10.24815/jdm.v9i2.25936

Development of Application Based on Augmented Reality to Improve Student's Spatial Ability

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Received: 17 May 2022; Revised: 22 September 2022; Accepted: 31 October 2022

Abstract. *Technology has become a crucial part of the learning process and a facilitator of the interaction between students and teachers. Spatial ability is a crucial ability in mathematics learning and success in STEM. In this case, Augmented Reality (AR) in mathematics learning can facilitate the abstraction of mathematics that represents a new representation of mathematics concept. The objectives of this study were to develop an application using AR which was further used to improve the spatial ability of Junior High School students. Meanwhile, the method used in this study was R&D using the ADDIE model and quantitative approach through t-test. In this case, 64 students of 8th grade in Junior High School were involved as the research samples, where 32 students were in the control class and 32 students were in the experimental class. The results of this study were that the AR application was feasible to use in mathematics learning and its application enabled teacher and students to learn solid geometry using Augmented Reality with the object that can be manipulated, interact in real-time, and measure objects in the real world. It was also obtained that the learning outcomes of students who used the application were higher than the learning outcomes of students who did not use application, indicating that the application could increase stdudents spatial ability.*

Keywords*: application, augmented reality, spatial ability*

Introduction

Technology has been used in the learning process for years. The use of ICT in the education sector has become a crucial part of the learning process for students inside as well as outside the classroom setting (Lawrence, 2015). Technology in learning is a connection between students and teachers worldwide. Technology aids the interaction of college students with fellows and teachers (Mohamedhoesein, 2017). In this case, smartphone has been used by many people around the world to do multifunctional daily activities. Based on the last survey from the ministry of communication and information shows that 70.98% of students/college students have smartphones (Kominfo, 2017). Students and teachers can use mobile device for mobile learning since it will enable students and teachers to learn anytime and anywhere. The definition of m-Learning itself is enabling the learning process without cable or physical connection, so the learning can be accessed anywhere (Georgiev, Georgieva, & Smrikarov, 2004). Nowadays, one of the types of mobile devices uses in the education process is a smartphone (Georgiev et al., 2004). The smartphone is used in learning for the last decade as a device in mobile learning. Based on the previous research (International Data Corporation/IDC, 2020) in 2019, 86.6% of smartphone users worldwide used the Android operating system. The use of the Android operating system in smartphone is massive because the Android operating system is open (open source). An open operating system can provide free software source code. It allows the developers to develop, distribute, and reproduce it without paying any license.

One of the current technologies is augmented reality. Augmented reality (AR) in real-time combines interaction, real object, and virtual objects with an enhancement of the real world by adding simulated elements (Azuma, 1997; Medina Herrera, Castro Pérez, & Juárez Ordóñez, 2019). Augmented reality can be displayed in any object that the developer builds and manipulate so it allows the students to conduct active learning by interacting with the object. Augmented reality that is designed properly by aligning virtual and physical information and paying attention to the learning environment can be effective multimedia (Sommerauer & Müller, 2014). According to Bruner (1966) (in Lestari & Yudhanegara, 2015), there are three cognitive development stages, those are the enactive stage, the iconic stage, and the symbolic stage. The enactive stage is the stage of active learning using concrete objects or real things. The iconic stage is the stage of learning presented (manifested) in visual imagery, pictures, or diagrams depicting concrete activities present at the enactive stage. Meanwhile, the symbolic stage is the learning stage manifested in abstract symbols, verbal symbols (letters, words, or sentences), mathematical symbols, or other abstract symbols. Introducing concepts with several different representations which include using virtual manipulatives, drawing problems, and symbolic representations help students to understand concepts (Mutawah, Thomas, Eid, Mahmoud, & Fateel, 2019).

AR has two types including location-based and vision-based. Location-based, namely providing digital media in the form of digital maps and physical areas is applied by utilizing GPS technology that has been installed on smartphones. Location-based media provides information, narrative, navigation, or building models relevant to the real world. Meanwhile, vision-based is displaying digital media in the form of virtual objects after placing the camera on a marker/object (QR code or 2D target). Augmented reality was adapted in many kinds of research. One of the research projects is the research carried out on augmented reality as multimedia (Santos, Lübke, Taketomi, Yamamoto, Rodrigo, Sandor, & Kato, 2016). Another study was also carried out aiming to teach mathematics and geometry concepts to students using augmented reality application Construct (Kaufmann, Schmalstieg, & Wagner, 2000). Augmented reality will make students easier to learn and get information about what students could not get from real objects, such as when some blocks were built, and all the surfaces were colored. Students will get problems when they try to know how many blocks are not being colored. In AR objects, it will be easier to unbuild the object and then rebuild it. The essence of constructivist learning is that student individually can find and transfer complex knowledge if the student wants his knowledge to be student's knowledge (Rifa'i & Anni, 2016). AR enables students to get more experiences so that students can build their knowledge. According to previous study, Silverman and Hoyos (2018) stated that virtual manipulatives have the following characteristics: manipulatively replicating concrete objects, providing an additional user experience that is relatively difficult to obtain on concrete objects such as duplicating and cutting, offering concept simulation, is flexible in use, and can be accessed without limits. The use of augmented reality is a new representation of the concept of learning with a virtual environment and provides opportunities for students to explore wider problems at hand, giving students various views/alternative views of the environment they encounter (Jedtke & Greefrath, 2019; Zhang, Cui, Shan, Qu, Zhang, Tu, & Wang, 2020).

Based on Indonesia's national examination on junior high school, some difficult problems encountered by the students are finding space diagonal in solid geometry, finding the volume of solid geometry, and applying surface area to solve surface area problems in solid geometry (Puspendik, 2019). Spatial ability is a crucial ability in mathematics, physics, and enginering learning, which is also basic for understanding and solving problems in real-world (Quintero, Salinas, González-Mendívil, & Ramírez, 2015). A child's cognitive development is affected by many factors such as problem-solving 3D modelling. In addition, spatial ability is also an important factor in its development (Šafhalter, Glodež, Šorgo, & Ploj Virtič, 2022). McGee (1979) defines that spatial ability is the ability to manipulate, rotate, or reverse the stimuli presented in the image. Hegarty (2014), and Taylor and Hutton (2013) on spatial ability and success in science and engineering showed a clear relationship between spatial intelligence and STEM success. According to Khine (2017), visual and spatial reasoning skills are new ways to identify correlation between students and careers in STEM. Several studies were conducted previously concerning this matter (Kell & Lubinski, 2013). In recent years, researchers have been studying possible solutions to improve STEM spatial ability and achievement (Stieff & Uttal, 2015). Hannafin, Marry, Jennifer, and Yingjie (2008) Another study found that students with high spatial ability were significantly more capable in mathematics. Therefore this study was carried out aiming to develop application using AR and to improve the spatial ability of Junior High School students through the use of AR application.

Method

The study method used as the basis of the study was mixed methods, namely Research and Development (R&D) method and the quantitative approach. This study further also used ADDIE (Analyze, Design, Develop, Implement, Evaluate) model (Branch, 2009). The ADDIE steps are as follows:

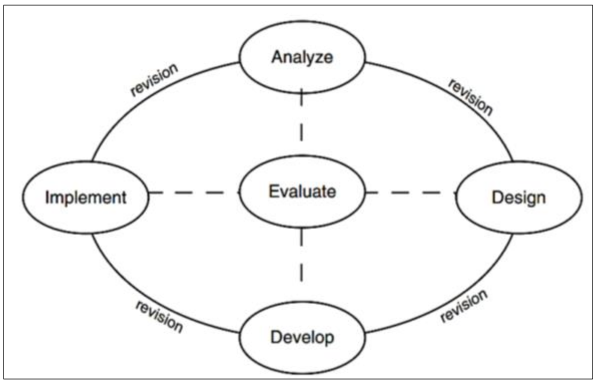


Figure 1. The ADDIE steps

Analyze step is a step on analyzing anything needed in developing mobile augmented reality application. This step included analyzing content, analyzing user needs, analyzing program content, analyzing minimum specification mobile, and analyzing how the applications work. The design step is a step of designing navigation, user interface, object 3d, and flowchart. Furthermore, the develop step is a step of developing everything from the analysis and design steps to become augmented reality mobile applications that are ready to use. This step included developing all user interfaces from the application opening by the user until the application closing by the user and product assessment by experts, teachers, and some students. The respondents in this step were chosen using purposive sampling. In this case, the experts were the media experts and mathematics education expert. Teachers involved were two mathematics teachers in junior high school. Furthermore, the samples were 64 students in SMPN 34 Semarang, in which 32 students participated in the control class and 32 students participated in the experimental class. The quality of product criteria referred to Bokhove and Dijvers assessment (Bokhove & Drijvers, 2011) by modifying algebraic criteria into mathematics criteria. Meanwhile, the assessment score referred to Likert scale with format Strongly Agree (WA) = 4, Agree (A) = 3, Disagree (D) = 2, and Strongly Disagree (WD) = 1. The assessment percentage for all response was further calculated by the following formula.

$$\text{Assessment Percentage}(\%) = \frac{\sum Score}{\sum Maximal\ Score} \times 100.$$

Table 1. Feasibility category

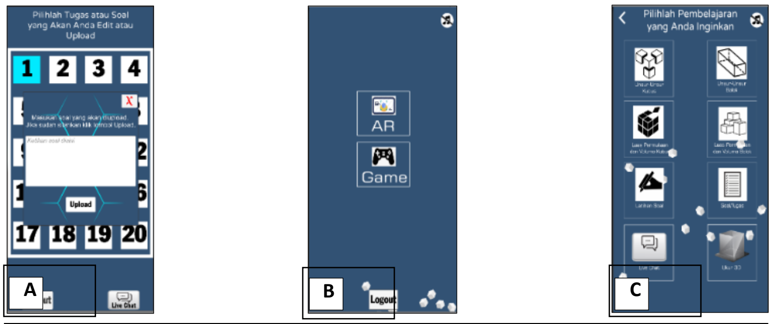
Formula	Category
Assessment Percentage$> 85\%$	Very Good
$70\% <$ Assessment Percentage $\leq 85\%$	Good
$55\% <$ Assessment Percentage $\leq 70\%$	Enough
$40\% <$ Assessment Percentage $\leq 55\%$	Poor
Assessment Percentage $\leq 40\%$	Very Poor

The feasibility category referred to the ideal conversion score (Widoyoko 2009). This feasibility category was used to develop step as the quality of product. This feasibility test related to the application feasibility and the worhty of the application that implement in the mathematics learning. The feasibility category from very less category until very good category (see Table 1).

The implementation stage was in the form of learning activities with application and direct trials in the learning process. The implementation step aimed to prepare the learning environment and involved students, as well as carry out the learning process. The implementation was considered successful after the students understood the online learning tools used. The selected online learning tools were the learning tools that were quite familiar to students, making it easier for students to operate these learning tools. In this case, the implementation of learning was in the forms of constructing solid geometry about cubes and cuboid in classes VIII D and VIII E at SMPN 34 Semarang. This study involved class VIII D as the control class and class VIII E as the experimental class. Learning through online classroom (Edmodo). Before participating in the learning, students were given a pretest question. Furthermore, the learning was carried out in 4 meetings. At the end of the learning process, the students were given a posttest and a questionnaire to provide an assessment of the application used. The learning was participated by 32 students in class VIII D and 32 students in class VIII E. In this case, the learning process in the experimental class used Project Based Learning wiith augmented reality-based application on the android operating system. Meanwhile, the learning process in the control class used Project Based Learning. Furthermore, the evaluation stage was a stage carried out at the end of the development process using the ADDIE model. The purpose of the evaluation stage was to assess the quality of learning products and processes, both before and after implementation (Branch, 2009). Evaluation before implementation, which was carried out at the analyze, design, develop, and implement stages was a formative evaluation, while evaluation which was carried out after the learning implementation was a summative evaluation. In this case, summative evaluation was carried out after implementation to determine the level of mastery of the material and the influence of application on the material that has been taught. Evaluation based on pretest and posttest in the control class and the experimental class.

Results and Discussion

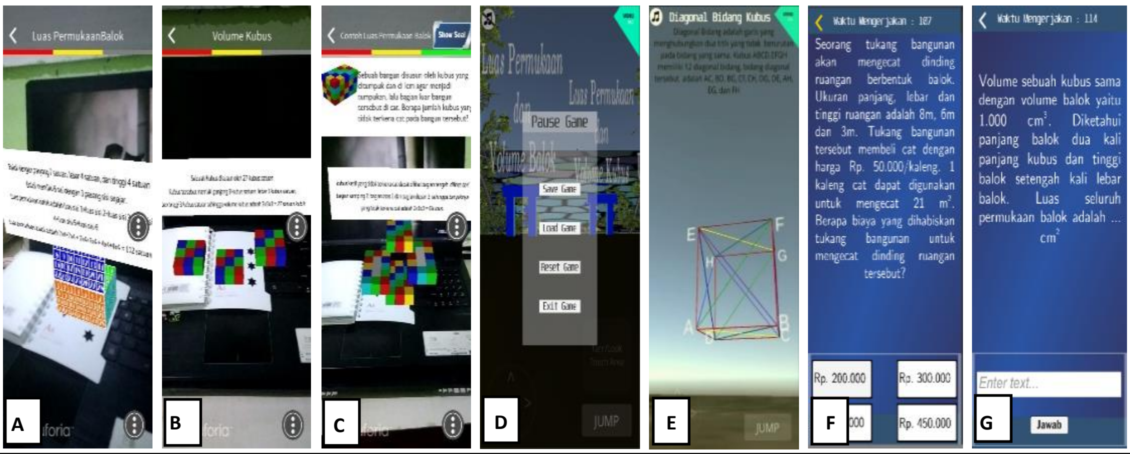
Based on this research, it was obtained that this application enabled the teacher and students to learn solid geometry using Augmented Reality with the object that can be manipulated, interact in real-time, and measured in the real world. These items were further collected and packed into one application. User Interface (UI) of the application is user view, it is important because this appearanence as first impression for the user. The application enabled the teacher to give students assignments online and collect all the student's answers online. All students answer were then uploaded to a database that can only be accessed by the admin, so the admin as a teacher can collect all the answer by going to the database account in firebase. The user who enterred from the sign-in menu would find options menu. The option menu presents AR and games. The subject menu presents learning and others feature also the user can choose which lessons are in the subject menu. UI application features after trials are shown below.



A. Admin/teacher Menu; B. Option Menu; C. Subject Menu

Figure 2. Application feature

AR for surface area and volume were provided for students to access surface area and volume of cube and cuboid in AR environment. AR for sample problem provided sample problem for students. Game feature is provided for students learn in virtual world using first person views. Furthermore, problems solving exercises provide two types of exercises, those are multiple-choice and short stuffing. In this case, all exercises are about surface area and volume of cube and cuboid problem-solving. So, it made the students try to solve problems as in real-life problems.



A. AR for Surface Area; B. AR for Volume C. AR for Sample Problem
D. Game Menu E. Game Feature F. Exercise Multiple Choice G. Exercise Short Stuffing

Figure 3. Learning features using augmented reality, game, and exercises

Live chat enables teachers and students to interact and discuss learning or some problems. Virtual measurement tools enable teacher and students to interact in the real world. Students and teacher could also measure real objects using virtual measuring tools in 2D tool or 3D tool. The 2D tool can be used to measure the length and width. The 3D tool can be used to measure length, width, and height. The marker for 3D measuring is special. It has been settled so that it can be used to measure a real object with minimum error. All 3D object in application such as cube and cuboid parts, surface area and volume of cube and cuboid can be manipulated by virtual touch (by touch the object in smartphone screen). This feature enable teacher and students to learn solid geometry in interactive way by manipulating the object. This application also enable students to measure real object use 3D or 2D measuring feature.

A. Live Chat Room
B. 2D Measuring Instrument C. 3D Measurement Instrument

Figure 4. Feature for exploration

The assessment of application was carried out by media experts, material experts, teachers, and 32 students. The assessment of application by material experts obtained an average of 93.75%, indicating that the application was in the very good category. The assessment of application by material experts obtained an average of 93.75%, indicating that the application was in the very good category. The assessment of application by two mathematics teachers obtained an average of 92.045%, indicating that the application was in the very good category as well. The assessment of application by 32 students obtained an average of 82.161%, indicating that the application was in the good category. The quality of the product was assessed by two teachers, a mathematics education expert, and a media expert. Furthermore, the implementation involved 32 students, with the following summary of the assessment from all respondents:

Table 2. Assessment of feasibility and validity

Assessment	Percentage	Category
Media Expert	90.625%	Very Good
Mathematics Education Expert	93.75%	Very Good
Teachers	92.045%	Very Good
Students	82,161%	Good

The assessment was carried out by media experts, mathematics education experts, teachers, and 32 students. The implementation of the application in 32 students has some difficulties like determining the marker for set augmented reality in the real world. On the other hand, students are interested and easily use the application.

Table 3. Recap feasibility and validty test

Criteria	Percentage	Category
Mathematics	85.166%	Very Good
Tools	91.504%	Very Good
Assessment	87.76%	Very Good
General	92.878%	Very Good
Total	89.325%	Very Good

The researcher was presenting the application to media experts, mathematics education expert, and teachers. The researcher did a recap of all feasibility test. The mathematics criteria obtained a percentage of 85.166%, indicating that it is included in the very good category. The mathematics criteria have been assessed and showed that the application can inform and deliver the mathematics concept to the students. The tools criteria obtained a percentage of 91.504%, which means that it is included in the very good category. The assessment criteria obtained a percentage of 92.878%, which means that it is included in the very good category. The general criteria obtained a percentage of 92.882%, which means that it is included in the very good category as well. Total recap assessment obtained percentage of 89.325%, which means it is included in the very good category.

The student's spatial ability test was further conducted and intended for the experimental class in order to determine the spatial ability of both control and experimental class students. Table 4 explains that the experiment and control class consisted of 32 students. The minimum criteria that used in this research was 70 as a standar because the Minimum Criteria of Mastery Learning of the population that research occur is 70. Based on the calculation results, it was found that the average spatial ability of students in the experimental class was 78.84, more than 70 so that they were completed individually and the proportion of of students who exceed the minimum criteria for spatial ability in the experimental class was 84.38%, more than 80% so that they were classically completed. The average spatial ability of students in the control clas was 72.19, more than 70 so that they were completed individually and the proportion of students who exceed the minimum criteria for spatial ability in the control class was 81.25%, more than 80% so that they were classically completed.

Table 4. Group statistics

	Code	N	Mean	Std. Deviation	Std. Error Mean
Score	Experiment	32	78.8438	8.28177	1.46402
	Control	32	72.1875	9.26122	1.63717

The results of the calculation of the difference between the two averages show on the table 5 obtaining Sig. (2-tailed) of 0.004 < 0.05. Therefore, it is considered that there is significant difference in the mean score of students' spatial ability of the experimental group and the control group. The mean score in table 4 further indicates that the mean of experimental class was higher than the control class.

Table 5. Independent sample test

		Levene's Test for Equality of Variances		t-test for Equality of Means					95% Confidence Interval of the Difference	
		F	Sig.	t	Df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
Score	Equal variances assumed	.069	.794	3.031	62	.004	6.65625	2.19629	2.26593	11.04657
	Equal variances not assumed			3.031	61.241	.004	6.65625	2.19629	2.26485	11.04765

The N-gain test aimed to determine whether the students' spatial ability in the experimental class has increased or not. In this case, the N-gain test show in table 6.

Table 6. N-gain test

Descriptives

	Class		Statistic	Std. Error
NGain_Percent	Experiment	Mean	61.9048	2.63742
		Std. Deviation	14.91947	
	Control	Mean	49.2825	2.84543
		Std. Deviation	16.09619	

Based on Table 6, the mean posttest score was better than the mean pretest score of the experimental class. It was obtained based on the calculation of the N-gain of 0.619048 and was included in the category of moderate increase so that it showed that there was an increase in spatial ability in the experimental class. The average N-gain of the control class students' spatial abilities were lower than the experimental class and the proportion of students who completed the control class was lower than the proportion of students who completed them in the experimental class. It means that there were more students in experimental class exceeded the Minimum Criteria of Mastery Learning than the students in control class.

In 3D design, there were cube and cuboid elements, surface area and volume of cube and cuboid, surface and volume sample problems of cube and cuboid, and 3D measuring object. In this case, the learning design was based on Bruner’s theory of enactive representation as learning using a concrete object, iconic representation as learning with visual imaginary, symbolic representation as learning with abstracts symbol, it can be verbal symbol or mathematics symbol or others abstract symbol (Bruner, 1966). Meanwhile, the learning design for the surface area and volume of a cuboid referredto Alexander and Koeberlein, (2011). Augmented reality presents 3-dimensional objects in the real world so that when they do not use application, students are accustomed to using their spatial abilities to describe 3-dimensional objects in the real world. This is supported by the report stated by Sudirman, Mellawaty, Yaniwati, and Indrawan (2020) that integrating the real world in augmented reality-based application had a positive impact on understanding mathematical concepts.

Furthermore, based on the independent sample t-test, the value of sig. (2-tailed) of 0.004 < 0.05, indicating that the mean score result of students' spatial ability using augmented reality-based application is significantly different from the average spatial ability of students who do not use augmented reality-based application. Differences in spatial ability results can be significantly different supported by the use of augmented reality application that invites students to use spatial abilities to the fullest. In addition, augmented reality makes it possible to build and associate ideas, represent and build connections, as well as analyze and extract ideas to develop spatial abilities (Elsayed & Al-Najrani, 2021).

The game features provide a learning experience in a virtual world for the user. The user plays as the first person. Users can access all learning and other features through games. The realization of the 3D object will make the 3D object just looks like a real object and transform into an animation object. Teachers must master the material, especially cube and cuboid and teachers must be fluent in using applications to convey material in the learning process. Students have a better understanding of the material and media provided by the teacher when the teacher masters the knowledge and how to convey it (Sowell, 1989). Nowadays, technologies enable learning with real objects to be replaced with real object as virtual objects that can be touched and moved to increase mathematical concepts. Concrete manipulatives can be used by students to introduce or develop a mathematical concept by touching and moving the object (Silverman & Hoyos, 2018).

Augmented reality also allows students to manipulate 3-dimensional objects that allow students to have various images when the object is rotated, enlarged, and shifted. Trial activities are assisted by online learning tools. The use of augmented reality supports academic achievement in online learning because it gives students more focus on learning than in online learning that does not use augmented reality (Eldokhny & Drwish, 2021).

This application can run properly on an android smartphone with a minimum operating system is Android Jellybean 4.1. Since the application needs some space in RAM to make the application run properly and the smartphone does not bse a heater while the application is running, the application must install in 1 GB minimum of RAM. Augmented reality is the technology that is effective in cost and provides attractive and active contents for students to improve spatial ability (Martín-Gutiérrez, Contero, & Alcañiz, 2015). The implementation of the application in learning practices can be implemented in many situations because the application doesn't need special requirements, mostly students' android phone now above 4.1, it shows in Figure 5.

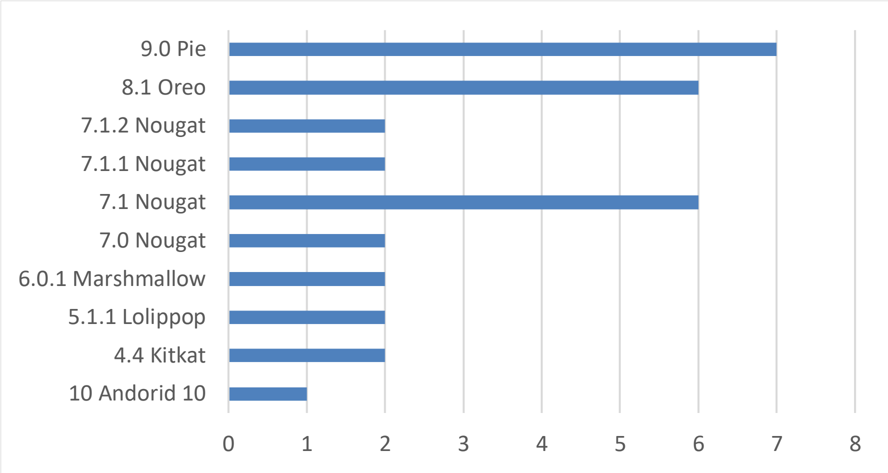


Figure 5. Students android version

The use of augmented reality also invites students to play an active role in the learning process because students are more interested and enthusiastic about learning using technology. Virtual manipulatives can provide more personal meaning and tasks, this is obtained from initial representations and experience after using virtual manipulatives to construct meanings of concrete and virtual objects or multiple representations (Osana & Duponsel, 2016). Students' interest in application is an important point that can be used by teachers to invite students to focus on learning and make students able to organize their knowledge independently and this is possible using augmented reality. The use of augmented reality improves the understanding of mathematics also the interest and interactivity of students in mathematics (Demitriadou, Stavroulia, & Lanitis, 2020).

Teachers can also give assignments by using the Admin/Teacher Menu as desired by the teacher so that teachers can measure students' abilities in real-time and can find out the learning process carried out. Good communication between students and teachers also needs to be implemented to ensure the learning process is running well and this can be facilitated using this online media. In addition, students and teacher can communicate freely use the Live Chat Room in real time but it needs internet connection to access it. The assessment from the media expert shown in the validity test that the application was very good but it must be revised in bring out the 3D object in the dark environment and the application has added flashlight facility and made application in one theme so the application in dark blue theme. The mathematics education expert and teachers in validity test further showed that the application was very good because the application can be manipulated. However, there were also some suggestions that cannot be implemented in appliction because of the lack of developer such as making the 3D object freely manipulated so the students can be more active in the learning process.

Conclusion

As shown in the result and discussion above, the application based on augmented reality on the android operating system can be considered as an alternative application for students and teachers. The 3D object in augmented reality can be shown anywhere without a special marker and manipulated. It will make students carry out active learning by choosing and manipulating the object. Custom assignment also enables teachers to send an assignment to students and collect their answers. Exercises problem-solving will further make students use double representation and increase problem-solving skills. Live chat features further allow the teachers and students interact in live chat and live conversation that allows teachers and students to discuss the learning process or problems encounterd. In addition, in the case, of 3D measurement, it allows students and teachers to increase their experiences with measuring a real object using a virtual object. The game feature allows students to learn in the virtual world. This application can run properly on an android smartphone with a minimum operating system is Android Jellybean 4.1. It enables application can be installed on many smartphones. Based on the results of the feasibility test of application, the test results of all respondents are in the good or very good category. The average spatial ability of students in the experimental class is higher than the average spatial ability of students in control class who do not use application. The application can increase students' spatial ability.

This study is limited to solid geometry, especially cube and cuboid. In addition, the application does not need special marker but students must prepare the proper marker. This augmented reality application is still early developed and implemented, so it still has much possibilities to develop. Therefore, we recommend to develop the augmented reality in game situation so students can be more challenged and motivated.

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