

Improving the Spatial Ability of Distance Learning Students on the Material of Three-Dimensional Shapes through Mobile Learning Applications Based on Augmented Reality

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ABSTRACT

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This research develops a mobile learning application that produces a feasible and attractive product to be used as a learning resource. Then, the product was tested quantitatively on users to determine the product's readiness and its relationship to increasing the user's spatial abilities. This research is a continuing research that has been carried out previously regarding the development of ABRAR (Application of three-dimensional shapes with Augmented Reality) application (Anam *et al.*, 2022). The product has been validated by content and media experts and has received positive feedback from student users. Data was collected in Nusa Tenggara: Regional Offices of UT Mataram and UT Kupang, involving 3.098 Elementary Education Study Program students. The sample size consisted of 310 respondents, determined using the Lemeshow formula. The product produced from this research is an augmented reality-based mobile learning application that serves as a learning resource. The results of the mobile learning media trial developed were interpreted as very positive. It shows that using mobile learning in geometry subjects provides a positive response and increases motivation in the learning process. In addition, the implementation of mobile learning in spatial ability has shown a 30% improvement in imagining the position of three-dimensional shapes. It indicates that mobile learning has influenced the respondents' spatial ability. Respondents can visualize three-dimensional shapes from a certain point of view by utilizing augmented reality (AR) technology. Furthermore, based on the feasibility test results, the resulting mobile learning meets the criteria of being excellent and feasible to use as a geometry learning medium. The result of the research is mobile learning application so that it can be applied for distance education with requirements has an Android application system and easy to connect the internet. Thus, the ABRAR application can support learning anytime and anywhere, improve understanding of the material, and improve students' spatial abilities.



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A. INTRODUCTION

Based on the 2019 PISA results, Indonesian students need to improve in geometry, gaining only 69.2% at level 1, 19.8% at level 2, 7.8% at level 3, and 0% at the high level (PISA, 2019). Meanwhile, it is known from the results of the TIMSS 2015 survey that Indonesian students are considered to have low achievement in the mathematics content domain and cognitive domain. For example, in the math content domain, students' geometry learning achievement only reached 20%, while those presented in the cognitive domain showed that Indonesian students'

learning achievement was only 25%. The results of the latest study conducted by the government through National Assessment of Educational Progress state that students' ability to read well has only reached 50%. Meanwhile, students' mathematical ability to answer correctly only reached 33% (Detik.edu, 2021). According to Anamova (2019), most students need help in learning geometry due to the lack of students' spatial abilities. These indicators: (1) the inability of students to describe two- and three-dimensional objects. According to empirical evidence, many students incorrectly draw three-dimensional objects in two dimensions or vice versa when sketching three-dimensional objects in two dimensions; (2) lack of creative spatial sensing, resulting in errors in spatial visualization; (3) reduced capacity to understand spatial objects in images; (4) reduced capacity to create visual representations in mind or utilize technology. According to empirical research on geometry learning in Indonesia and internationally, low Spatial Ability causes sub-standard learning outcomes in schools (Risma *et al.*, 2013).

Previous research has shown that spatial ability can be improved through new technologies such as Augmented Reality by creating interactive three-dimensional environments in math lessons. In addition, learners can better understand mathematical concepts about two- and three-dimensional geometry through AR tools with a series of learning stages (Chen, 2019; Elsayed & Al-Najrani, 2021; Flores-Bascuñana *et al.*, 2020). AR displays can dynamically give learners a variety of three-dimensional structures to work with, as they can be created virtually without the physical constraints of the real world.

One of the newest learning innovations that has become a concern and is growing rapidly to be implemented is a visual technology-based learning model in the form of digital objects from the representation of real objects. One example of such technology is augmented reality (AR) technology. AR technology is a method that applies objects or the virtual world to the real world (Milgram *et al.*, 1995). AR technology as a learning medium has special potential, namely being able to display information in all forms of media virtually, which other technologies cannot achieve (Baus & Bouchard, 2014).

AR technology can also improve students' learning skills in thinking critically, communicatively, and selectively (Dunleavy & Dede, 2014). Research on the implementation of AR as a learning media has been realized at every level of education with various topics, such as the optimization of conventional learning media, the effect of AR on learning outcomes, and functional technical testing of AR systems. Another important factor to consider from the implementation of AR is the evaluation of the level of user acceptance in the form of testing on the dimensions of user interface (UI) and user experience (UX). Usability testing aims to assess the ability to implement an AR product effectively and efficiently by identifying issues that can arise during testing.

Based on research conducted by Rohendi & Wihardi (2020), it is known that students still find it difficult to construct geometric spaces, especially to solve problems with visualization. This visualization is one of the elements of mathematical spatial ability proposed by Xie *et al.* (2020). To overcome the lack of mathematical spatial ability of students, learning three-dimensional shapes material often uses learning media. The use of learning media is becoming increasingly diverse and interactive, an example that is currently popular is the use of augmented reality technology.

Previous research on AR proves that AR makes learning more effective, and children are more excited, like the research conducted by Khotimah and Satiti (2019), who utilized AR learning media. According to the study, students have a very positive response to the AR-based learning media developed because it is categorized as practical and follows the character of students who cannot be separated from their gadgets. As many as 87% of students achieved the value of learning completeness criteria, so AR-based learning media was categorized as effective. It is also in line with the results of research by Sungkur, Panchoo, and Bhoyroo (2016), which states that AR applications have been shown to help students understand complex concepts that are generally an obstacle to students in understanding geometry material. Through AR, learning has been brought to a new dimension because learners can easily visualize what is happening and understand complex concepts. Another study by Nurhasanah *et al.* (2019) showed that AR can positively impact students' understanding of science concepts. Based on the results of data analysis using a *non-equivalent control group design*, it shows differences between classes that use AR media and classes that do not use AR media in the science learning process.

Thomas and David in 1992 in Akçayır & Akçayır (2017) explained that AR technology could work on several supporting factors, namely *sensing* and *registration*, as well as interactive and *display systems*. *Sensing* and *registration* are used to create graphics from several perspectives because interactive technology is used to manipulate objects with *interface control*, and *display systems* are used to connect the real world with the virtual world. In math learning, students are required to experience themselves, seek the truth, and draw conclusions from the learning process they experience. Di & Zheng (2022) stated that learning media using AR effectively improves students' spatial abilities. Widada *et al.* (2021) also stated that learning geometry with AR in the Geogebra application improves students' spatial abilities and concept understanding.

Based on this description, the research that has been done previously occurred to students in face-to-face learning, while this research is implemented in distance education. The characteristic of distance education is the separation of students and lecturers in the learning process. Students can utilize various learning materials available with their learning patterns and strategies. According to Moore and Kearsley (2011), there are three types of interactions that need to be known by distance learning practitioners, namely interaction between students - teaching materials, interaction between students - tutors, and interaction among students. It is often found that institutions that organize distance education only focus on developing one type of interaction so that other types of interaction could be better developed. It must be avoided considering that students in distance education have different learning styles.

Some distance learning students tend to study on their own according to the time and opportunities they have. They tend to interact directly with the course material they take. They have few opportunities to interact with lecturers/tutors or fellow students. Distance learning must provide good teaching materials or a learning medium that allows students to interact and understand the course material well so that students can optimally interact with the material.

Based on the description above, the problem formulation in this study is how the implementation of AR-based mobile learning development on three-dimensional shapes

material has been developed on students' spatial abilities on three-dimensional material. Then, the product was tested quantitatively on users to determine the product's readiness and its relationship to increasing the user's spatial abilities. This research is expected to benefit users, especially students, in understanding the intricacies of three-dimensional shapes material more quickly and flexibly using AR-based applications. Based on this, mobile learning is suitable for use in the current condition of students to be applied as concrete and interesting learning material especially for distance education.

B. METHODS

This research design is evaluative and descriptive, which is research to measure and explain the success of a particular product so that it can be concluded that it is feasible, relevant, effective, and efficient (Siedlecki, 2020). This research continues a series of testing processes for an AR-based learning media for three-dimensional shapes material in the Mathematics Education II course (Anam *et al.*, 2022). This research uses quantitative methods to test the relationship between application use and increased user spatial abilities. In previous research, practical testing was carried out by experts with good interpretation results. This study used a questionnaire distribution technique for respondents who were determined *non-randomly* (*non-random sampling*).

The respondents selected in this study consisted of two categories, namely experts and the general public. Respondents in the expert category were teaching staff (teachers and lecturers), while general category respondents were students who took distance education at Universitas Terbuka. The selection of respondents was determined by their professional background in mathematics education, primary teacher education, or technology so that they could assess or evaluate learning media products. Data was collected in the Nusa Tenggara region, including Mataram City (NTB) and Kupang City (NTT). Based on observations made by researchers in April, the two regions are still minimal in using learning media when studying three-dimensional shapes material. The number of Elementary Education students at UT Mataram Region is 941, and at UT Kupang Region is 2,157, so the number of Elementary Education students in Nusa Tenggara is 3,098. The sample size was 10% of the population according to the Lameshow formula, so the respondents were 310 students. The sampling technique used quota sampling.

The data collection technique in this study used a questionnaire. The questionnaire data obtained were then processed and analyzed to serve as a reference in developing mobile learning media. The data analysis technique used in this research was quantitative descriptive analysis which aimed to quantify the questionnaire results following the indicators determined by giving a predetermined score weight. This analysis was used to describe the characteristics of each data obtained. The results of data analysis are used for application revision to perfect the application being developed. In this study, the rating scale used in the research instrument is a *Likert scale* with a scale of 1 to 4.

The calculation results obtained in the form of percentages are then categorized according to the criteria using a rating scale to determine the feasibility level of the developed application. The developed product can be suitable if the interpretation is $\geq 60\%$ based on calculating scores

according to the *Likert* scale (Riduwan, 2012). Descriptive quality criteria with a rating scale are presented in Table 1.

Table 1. Quality Descriptive Criteria with *RatingScale*

Assessment Level	Description
Figures 0-20%	Very Poor
Figure 21-40%	Poor
41-60%	Fair
61-80%	Good
81-100%	Very good

C. RESULT AND DISCUSSION

The result of this research is a mobile learning application that can be accessed using a smartphone with an Android operating system named "ABRAR: Application of three-dimensional shapes with Augmented Reality". The content in this media consists of AR simulations, materials, learning videos, quizzes, three-dimensional shapes calculators, and information product following the analysis of student needs. This research is a continuing research that has been carried out previously regarding the development of ABRAR application (Anam *et al.*, 2022). The development consists of three stages: *preliminary product development*, *preliminary field testing*, and *main product revision*. The preliminary product development stage involved making an image design for the mobile learning display. The following image is the display design of ABRAR application that has been created, as shown in Figure 1.



Figure 1. Mobile Learning Display (A) Application Start Page (B) Application Main Page

The preliminary field testing stage involved media, material, and language experts to discover the shortcomings of the application being developed so that revisions could be made. After that, the main product revision stage was conducted by improving the mobile learning application based on the experts' input. The preliminary field testing and main product revision stages are combined into one stage with the experts' discussion on the app's appropriateness. The feasibility of the mobile learning application that has been developed needs to be tested practically. The overall average assessment results for the suitability of this mobile learning media was 85.4% with the interpretation of "Very Good". The overall average assessment result for the suitability of this mobile learning language was 78.8% with the interpretation "Good". The overall average assessment result for this mobile learning media material was 79.7% with the interpretation "Good".

The discussion in the research is still in the main product revision stage which focuses on field testing for students. This section produces the quality and feasibility of a mobile learning application that is ready to be tested by students sampled as users of this mobile learning application. The following are the results of the AR-based mobile learning development implementation analysis on the material of three-dimensional shapes that have been developed for students' spatial abilities on three-dimensional material.

1. Feasibility Test of Mobile Learning

The empirical media feasibility test or media trial aims to test the feasibility of the media and find out the opinions of *mobile learning* media users that have been developed. Media trials were conducted on 310 respondents from the Universitas Terbuka Elementary Education Study Program from the Nusa Tenggara region who used smartphones based on the Android operating system. In the first step, the researcher provided a *Google Drive* link containing the application "ABRAR: Application of three-dimensional shapes with *Augmented Reality* " to respondents via WhatsApp Group. After the application is installed, respondents can explore the downloaded application. Furthermore, respondents were given a written media trial questionnaire to provide an assessment of the *mobile learning* that had been developed. The questionnaire consisted of 34 questions divided into seven aspects assessed in the media trial by the respondents, namely aspects of content feasibility in mobile learning media, presentation feasibility in mobile learning media, language suitability in mobile learning media, use of AR technology in mobile learning media, usefulness, visual and audio appearance of mobile learning, as well as implementation and software engineering. Based on the calculation, the results of the media trial can be seen in Table 2.

Table 2. The Results of Small-Scale Media Trial by Learners

No.	Aspects	Question Item	Average percentage (%)	Criteria
1	The Feasibility of Mobile Learning Content	1 to 4	87,9	Very good
2	The Feasibility of Mobile Learning Presentation	5 to 10	89,7	Very good
3	The Suitability of Mobile Learning Language	12 to 15	88,8	Very good
4	The Use of AR in Mobile Learning	11, 16, and 17	91,7	Very good
5	Usability	18 to 21	89,6	Very good
6	The Visual and Audio Display of Mobile Learning	22 to 31	89,5	Very good
7	The implement ability and Software Engineering	32 to 34	85,6	Very good
Average Overall Score			89.0	Very good

The description of the ABRAR mobile learning media trial results is as follows:

a. The Feasibility of Mobile Learning Content

The content feasibility aspect of this mobile learning media consists of four questions divided into two indicators: the suitability of the material with the basic competencies and the accuracy of the material content. Based on the average percentage of the

feasibility of each indicator, it was obtained at 87.9%. It means the content feasibility testing process on mobile learning ABRAR has met the "Very Good" criteria.

b. The Feasibility of Mobile Learning Presentation

The presentation feasibility aspect of this mobile learning media consists of six questions with two indicators: material presentation techniques and material presentation support. Based on each indicator's average percentage of feasibility, it is 89.7%. The percentage shows that the content feasibility of ABRAR mobile learning has met the "Very Good" criteria.

c. The Suitability of Mobile Learning Language

The language suitability aspect of this mobile learning media consists of four questions with four indicators: sentence effectiveness, communicative, dialogic and interactive, and conformity with language rules. Based on each indicator's average feasibility percentage, 88.8% was obtained. The percentage shows that the language suitability has met the "Very Good" criteria in this ABRAR mobile learning.

d. The Use of AR in Mobile Learning

The aspect of using AR in ABRAR mobile learning consists of three questions with one indicator: AR component. Based on each indicator's average percentage of feasibility, it is 91.7%. AR has met the "Very Good" criteria in mobile learning.

e. Usability

This aspect of usefulness consists of four questions with two indicators, namely the ability of the media to help learn the material of three-dimensional shapes and the user's (students) interest in the material after using mobile learning. Based on the average percentage of the feasibility of each indicator, it is obtained at 89.6%. This percentage means that the usefulness of this mobile learning media has met the "Very Good" criteria.

f. The Visual and Audio Display of Mobile Learning

The aspects assessed in the visual and audio appearance of this mobile learning ABRAR consist of ten questions with five indicators: layout accuracy, design suitability, clarity of images, writing, and video quality. Based on each indicator's average feasibility percentage, 89.5% was obtained. The percentage shows that the visual and audio appearance of ABRAR mobile learning is "Very Good".

g. The implement ability and Software Engineering

This aspect of implementation and software engineering consists of three questions with one indicator: the media's ease of use. Based on the average percentage of the feasibility of each indicator, 85.6% was obtained. It means the implementation and software engineering are "Very Good" and have met these criteria.

Based on the percentage results of the seven aspects, the overall average assessment of this mobile learning media is 89.0% with the interpretation of "Very Good". The aspect with the highest average score is using AR on mobile learning media, which is 91.7%. It proves that using AR in three-dimensional shapes material has a positive response because it can increase motivation in the learning process. It is in line with the research of Sungkur, Panchoo, and Bhoyroo (2016) results of his research are that AR applications have proven to help understand complex concepts that the average learner needs help understanding. Through AR, learning has

been brought to a new dimension because learners can easily visualize what is happening and understand complex concepts. Another study by Nurhasanah also showed that AR could positively impact learners' understanding of science concepts. (Nurhasanah *et al.*, 2019). In addition to the ratings, respondents also provided suggestions and comments as follows:

"It is good and I feel that I can understand the learning more easily, complete it with music backsound to make it interesting." (Respondent's Suggestions and Comments 28, 2023)

"Mobile learning is good, but it would be nice if mobile learning can also be accessed with IOS and can be downloaded from the Appstore." (Respondent 8's Suggestions and Comments, 2023)

Respondents gave compliments and suggestions regarding mobile learning that can be accessed using IOS, music background, bugs, and display colors. The media will be improved according to the suggestions and comments given. Since the researchers themselves developed mobile learning, it does not have official permission to be installed on IOS and uploaded to Appstore.

2. The Effect Mobile Learning on Spatial Ability

AR-based media helps students understand abstract mathematical material by displaying its visualization. AR displays can also help learners to foster spatial visualization skills, namely the ability to imagine changes in shape or changes in the place of three-dimensional shapes. In addition, the 3D AR display can allow learners to see changes in the shape of objects from various perceptions. This ability is commonly referred to as spatial perception ability. Thus, AR-based media can cover the weaknesses of conventional media, namely the use of blackboards to draw spatial shapes from various perceptions. Therefore, this section analyzes the effect of ABRAR mobile learning created using AR technology on the spatial ability of respondents who use it. Based on the results of the respondents' spatial ability test before and after using ABRAR mobile learning, the results are as Shown in Table 3.

Table 3. The Results of the Questionnaire Pretest & Post-test

No.	Questionnaire									
	1	2	3	4	5	6	7	8	9	10
Pretest	76	79	77	88	77	80	78	76	80	91
Average (%)	50.7	52.7	51.3	58.7	51.3	53.3	52.0	50.7	53.3	60.7
Posttest	106	116	111	108	121	125	114	110	114	131
Average (%)	70.7	77.3	74.0	72.0	80.7	83.3	76.0	73.3	76.0	87.3

The data above is the initial condition of respondents' knowledge of the material. Based on this data, it is known that most respondents already know about the concept of three-dimensional shapes beforehand. It can be seen from the overall average percentage, which shows a number above 50%. Furthermore, respondents were introduced to the ABRAR application that had been developed for the learning process of three-dimensional shapes. After that, a post-test was conducted to compare respondents' knowledge of three-dimensional shapes before and after using the application. It can be seen in the following post-test results.

After using ABRAR mobile learning, the respondents' knowledge of the material of the three-dimensional shape increased by 13-30%. The most significant increase of 30% occurred in the ability to imagine the position of three-dimensional shapes (Questionnaire 6). It proves that ABRAR mobile learning has influenced the respondents' spatial ability. Respondents can also imagine the three-dimensional shapes from a certain point of view. Using AR technology, respondents can visualize the three-dimensional shapes they want to observe. Therefore, the three-dimensional shapes can be observed from various sides to give respondents a real learning experience.

Students can improve their spatial abilities and problem-solving skills using AR-based learning media (Herman *et al.*, 2023). Mursyidah (2022) states that spatial ability is divided into three parts, namely (1) the ability to perceive, namely the ability to capture and understand something through the five senses; (2) the ability of the eye, especially color and space; and (3) the ability to transform, namely the ability to change the form of things captured by the eye into other forms such as observing, recording, interpreting in mind and then pouring the recording and interpretation into paintings, sketches, and collages. Students need these abilities to learn three-dimensional shapes (İbili *et al.*, 2020).

The results of this study indicate that learning through smartphones, especially AR-assisted teaching materials is very practical in accommodating students' spatial abilities. Respondents felt the ABRAR application positively impacted students and welcomed it if implemented in learning. The limitations of this study consist of a limited sample of subjects or respondents. In addition, respondents who did not have Android felt disadvantaged because they could not download the ABRAR application, so they needed more opportunities to learn using the application. For further research, the effect of Mobile Learning AR on distance learning students' spatial abilities can be compared using a control class and an experimental class.

D. CONCLUSION AND SUGGESTIONS

Students who take part in distance education can understand the intricacies of three-dimensional shapes material more quickly and flexibly using AR-based devices through learning components contained in mobile learning. The development of this mobile learning application produces a feasible, interesting product. It is more likely to be applied as a learning resource in the classroom because material and media experts validate the product and get an assessment from students as users. This research includes the process of product development and validation. The product produced in this research is a learning resource in the form of a mobile learning-based application expected to improve spatial abilities and understanding of three-dimensional shapes materials.

The overall average media trial percentage results of ABRAR mobile learning media: three-dimensional shapes AR application is 89.0% with the interpretation of "Very Good". The aspect with the highest average score is using AR in mobile learning media, which is 91.7%. It proves that using AR in three-dimensional shapes material has a positive response because it can increase motivation in the learning process. After that, the implementation of ABRAR on spatial ability was conducted, and it was found that the most significant increase of 30% occurred in the ability to imagine the position of three-dimensional shapes. It proves that ABRAR mobile learning has influenced the respondents' spatial ability. Respondents can also imagine a three-

dimensional shape from a certain point of view. Using AR technology, respondents can visualize the three-dimensional shapes they want to observe.

Based on the results of the mobile learning feasibility test, it can be concluded that the mobile learning ABRAR produced meets the very good criteria and is suitable for use as a learning media on the material of three-dimensional shapes. This media can support learning because it uses AR technology that, in addition to increasing knowledge of the material, can also hone students' spatial abilities. The mobile learning media "ABRAR" can be utilized as a learning support in learning the material of three-dimensional shapes anytime and anywhere. The drawback of making this application is that it is only available for Android and can only use a smartphone connected to the internet to download the application. Future research might be able to develop these shortcomings so that this application can become a good distance learning medium.

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