



Designing learning material assisted by augmented reality to improve spatial thinking skills

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Article Information

Submitted Nov 26, 2022

Revised Dec 10, 2022

Accepted Dec 30, 2022

Keywords

Spatial Thinkings
Augmented Reality
Geometry
GeoGebra
Mathematics

Abstract

Spatial thinking is a crucial ability to be mastered by students. On the other hand, the rapid development of technology in education, such as augmented reality (AR), is predicted to increase significantly in 2035. This technology should be utilized to provide new insights for students. However, the condition of learning resources related to AR currently needs to be improved. This study aims to design mathematics teaching materials on geometry materials using AR to improve spatial thinking skills. This study uses the Plomp model development research, which consists of three stages: preliminary, prototyping, and assessment. It is important to note that this paper reports results from preliminary. This article reports by collecting data through literature studies and questionnaires to mathematics teachers in the Rokan Hulu district. The findings reveal that the use of GeoGebra as an AR builder in Indonesia still needs to be created because of the excellent potential of Geogebra. AR learning resources on geometry at the high school level also need to be improved. Teachers agree that learning using technology has become necessary and are interested in using AR, especially in the geometry field. Based on the findings, we designed and developed Geogebra AR-assisted teaching materials based on these findings to improve spatial thinking skills.

INTRODUCTION

The rapid development of technology over the last decade has forced many sectors to adapt to the situation. The development of digital has also coincided with technology, which has seen increased use in the education sector, especially since the 2019 COVID pandemic. The use of technology in education today has become a necessity because the current generation needs to be educated with the old learning methods (Elsayed & Al-Najrani, 2021). Today can be seen in the many students interacting with their gadgets, so technology and digital learning should be provided.

Education in Indonesia, which initially still used traditional methods, is slowly beginning to adapt to new situations where technology must be used to stay connected, even if it is not in a real space. Teachers and educators must learn and improve their competencies to use technology effectively to achieve the learning goals they seek to achieve as much as possible. In addition, technology plays an essential role in learning as it helps in skill acquisition and can also be used as a motivating factor for the current generation of students (Rashevskaya et al., 2020).

One of the uses of technology in learning is augmented reality (AR). Over the past decade, the discussion of Augmented Reality (AR) has increased worldwide. This increase is in line with the growing popularity of smart devices and the dramatic increase in the development of

AR technology in our daily lives (Ahmad & Junaini, 2022). In fact, according to projections, augmented reality content will reach \$182 billion in 2035 (Mangina, 2018), this shows that the potential of AR is enormous and will reach an ever-broader range. One area where AR technology can be leveraged is education. AR can be an effective way to present self-constructed objects and can be presented in real-time simultaneously. It has been used in many fields of education, such as biology, chemistry, physics, and mathematics.

AR displays physical objects in real time by adding objects from the virtual world and adding information to existing natural objects (Amir et al., 2020; Cahyono et al., 2020; Mailizar & Johar, 2021; Vakaliuk et al., 2020). This digital technology allows existing real and virtual objects to be combined and displayed on digital devices such as tablets and smartphones. This AR feature is good because mobile devices allow students to access learning resources anytime, anywhere (Del Cerro & Méndez, 2021). Additionally, augmented reality allows the addition of 2D and 3D shapes and the ability to combine audio, video, and text files, making it easy to integrate digital content for user insight into the physical world (Elsayed & Al-Najrani, 2021; Vakaliuk et al., 2020). Using digital information in AR also improves the user experience (Ahmad & Junaini, 2022). Students can react and manipulate (Vakaliuk et al., 2020).

By incorporating AR technology into learning, the evolution of the educational paradigm has become possible. It is intended for students to generate knowledge using this technology interactively. There have been some changes in the application of AR in learning. In other words, students have now changed from recipients of knowledge to providers, and teachers have taken on the role of guides and tutors (Del Cerro & Méndez, 2021). AR was initially seen as an expensive technology, but now with free access to AR, it is much more likely to be used by teachers and students (Mailizar & Johar, 2021). From a learning perspective, interesting AR technology also allows users to experience digital and physical content or material, as it differs from standard media formats such as video and hard copy (Pellas & Kazanidis, 2019).

Many mathematics learning topics have utilized AR, such as geometry, algebra, probability, and statistics. However, the results of Ahmad's research show that most geometric materials use AR (Ahmad & Junaini, 2020). By using AR in the mathematics learning process and complementing it with appropriate visual information, we can build visual models of learning materials that interest students (Vakaliuk et al., 2020). Students can use their smartphone's camera to experience the fusion of the teacher-designed virtual environment with the real world because cameras may be performed outside the classroom depending on learning needs (Del Cerro & Méndez, 2021).

One of the abilities related to AR technology is spatial thinking. According to the NRC, spatial thinking is a constructive combination of cognitive skills consisting of knowing spatial concepts, using representational tools, and applying reasoning processes (Gagnier et al., 2022; Metoyer et al., 2015). On the other hand, according to Newcombe, spatial thinking pays attention to objects' position, shapes, relationships, and paths they take (Lane & Sorby, 2022). The ability to think spatially is used to imagine and manipulate objects in mind by combining three components: spatial, representational, and reasoning (Elfa et al., 2021). Spatial thinking allows people to use space to model the world (real and theoretical), structure problems, find answers, and express and communicate solutions.

Moore Russo et al. briefly describe the three components of spatial literacy: visualize, reason, and communicate. Visualization helps people create cognitive representations, allowing

them to see and understand the properties of spatial objects in their minds. When we visualize a spatial object, it may exist physically. By physically manipulating it, moving around it, and looking at it from different directions, we understand its spatial properties, which can be deepened. Spatial objects may not physically exist but may appear on a flat surface, such as a photograph, map, or drawing. Reasoning about spatial objects involves mentally manipulating internal representations and imagining changes in objects, such as cutting parts, forming judgments, and reasoning. The communicative component of spatial thinking includes exchanging information through interaction with oneself or others by describing spatial objects and manipulating them using sketching, computer modeling, physical modeling, cues, and verbal dialogue (Lane & Sorby, 2022).

Spatial thinking skills are essential in studying several branches of science, including mathematics, science, architectural engineering, astronomy, and others. In mathematics education, spatial thinking can help students understand and solve problems involving geometric concepts, such as shape, size, position, and spatial relationships. Students can use spatial thinking skills to visualize and manipulate 3D shapes in their minds, which can help them understand properties such as volume, surface area, and spatial relationships between different shapes. Spatial abilities are also needed to master work skills. For example, an architect needs spatial skills to design buildings, and a mechanic needs spatial abilities to assemble or repair damaged machine parts (Yuliardi & Rosjanuardi, 2021). Another example in everyday life is when we search for a specific location (for example, where is the position of a cinema inside a supermarket) (Gagnier et al., 2022).

NCTM emphasizes the importance of spatial abilities, 2D and 3D geometric activities, and representing geometric figures. Low spatial abilities are reported to cause students to drop out of school (Nagy-Kondor & Esmailnia, 2022). Based on (Gilligan-Lee et al., 2022), there is evidence showing that spatial skills strongly correlate with students' mathematical performance. Spatial ability is also considered the core ability to solve mathematical problems in geometry (Elfa et al., 2021). However, spatial abilities can be grown through learning (Gilligan-Lee et al., 2022) because having well-developed spatial thinking skills makes learning mathematics more exciting and straightforward. Moreover, for teachers, spatial thinking skills make it possible to visualize teaching materials and make mathematics easier to understand (Rashevskaya et al., 2020).

One way to grow spatial thinking skills is to use AR technology. Several research results show that AR has the potential to improve students' spatial thinking skills. The study's results (Ozcakir & Cakiroglu, 2021) show that augmented reality helps increase the use of mobile devices so that learning resources are not only in the form of books, communication, or playing games but also as a supporting mechanism for learning mathematics. Meanwhile, the results of research (Anggraini et al., 2020) show that learning mathematics with AR learning media can improve critical thinking and self-confidence, facilitate student-centered learning and problem-solving, and create interactive learning. In addition, AR has a feature to make objects dynamic. Using this feature, students can understand the position of objects in space and how to imagine objects that change or move. Therefore, students' spatial reasoning can be improved (Pangestu & Setyaningrum, 2020). Research results (Schutera et al., 2021) show that AR also helps students' spatial imagination, which may be challenging to realize when learning 2D material is traditional.

Based on the importance of spatial thinking skills for students, the benefits of using technology in learning, the potential use of AR, and the link between AR and spatial thinking skills, this research aims to develop AR-assisted teaching materials to improve students' spatial thinking skills.

METHODS

This is a developmental research project employing (Plomp, 2013). The model consists of three phases, namely: (a) the preliminary phase, by conducting needs and context analysis, reviewing the literature, and developing a conceptual or theoretical framework for research; (b) the prototyping phase, a research microcycle-based iterative design process with formative evaluation to improve and fine-tune the intervention at each stage; and (c) assessment phase, the goal of this phase is to determine whether the intervention or solution satisfies predetermined criteria. Typically, proposals for better interventions come out of this phase. The steps of the Plomp and Nieveen development model are as follows in Figure 1:

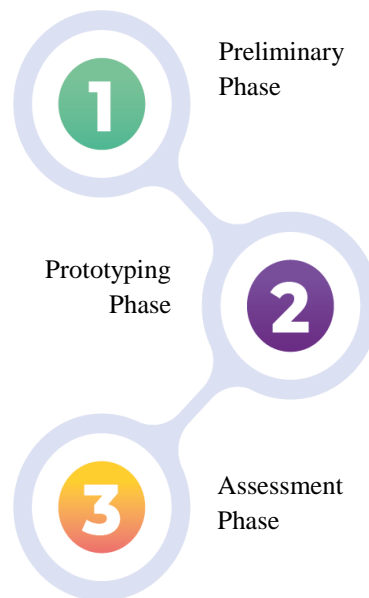


Figure 1. Model Plomp Development

This paper reports the results from the preliminary phase. In this phase, a systematic literature review of 26 selected articles was conducted to look at AR research trends and answer the research questions to obtain comprehensive information regarding the use of AR in mathematics learning in Indonesia. However, only articles meeting the following inclusion criteria were selected:

1. Published in an academic journal indexed by Google Scholar with titles involving AR and Mathematics.
2. An article based on research results published in a journal, not in a university repository or literature review.
3. Discuss the implementation of AR for learning mathematics.
4. Published for the last ten years, i.e., 2011-2021.

In addition, we also distributed a questionnaire to explore teachers' views on the need for AR. A total of eight math teachers in Rokan Hulu participated in this phase. The schools were randomly selected. Data were analyzed through quantitative and qualitative descriptive analysis.

RESULTS AND DISCUSSION

The results of this study are divided into two parts, namely the literature review and the questionnaire given to teachers. The following results are obtained based on research questions.

RQ1: What are the most popular types of AR development tools used for learning mathematics in Indonesia?

In general, AR can be divided into two types: marker-based and non-marker-based (location-based) (Fernández-Enríquez & Delgado-Martín, 2020; Ahmad & Junaini, 2020). The concept of usage is that when the AR camera point at an object set as a marker, the created digital information is displayed on the marker. Non-marker-based AR takes advantage of location when new information is activated by elements of the device that indicate its position, such as geolocation (provided by Global Positioning System (GPS), GLONASS, and Global Navigation Satellite System). Based on a search of articles related to the type of AR used, generally, research in Indonesia uses markers to display digital information. From 26 reviewed Indonesian articles, the graph of the type of AR used is shown in Figure 2.

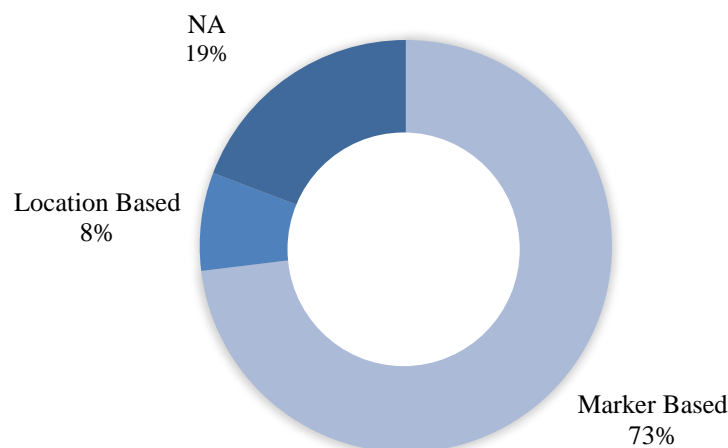


Figure 2. Distribution of AR Development Tools

Based on the graph, marker-based AR is the most widely used in research, while non-marker-based AR is only 8%.

RQ2: What are the popular AR tools to develop mathematics applications?

Several applications are needed to produce AR teaching materials, such as 3D object builders, applications that can export 3D images into markers, and AR cameras that are used to display AR-based digital objects/information. There are three popular AR builder applications include:

1. Unity 3D and Vuforia.

Vuforia is software for creating AR. Vuforia uses a computational algorithm that enables the application to recognize different types of markers (also known as "ImageTargets") in two (for example, QR codes) and two-dimensional images. When Vuforia recognizes a marker, accurate digital information is displayed to the user (Fernández-Enríquez & Delgado-Martín, 2020). Meanwhile, the unity 3D application is used to create a three-dimensional model and an application that can connect with vuforia. This application combination is dominant in several research articles (Ahmad & Junaini, 2020). However, some require additional applications such as Blender, Adobe Illustrator, Corel Draw, and others.

2. Assemblr EDU

Assemblr EDU is an AR-building application that can be installed on smartphones or tablets using Android and IOS operating systems. This application can also be accessed using the web. Assemblr allows educators to create teaching materials in the form of 3D or AR and can use materials that have been developed. This application also has a community and can be connected to other applications, such as Google Classroom, so educators can share AR content built on Assemblr using Google Classroom.

3. GeoGebra

GeoGebra is a powerful free software developed by Markus Hohenwarter and can be accessed through a smartphone, tablet, computer applications, or the web. GeoGebra has two views: the algebra view and the geometry view. Currently, the AR builder feature is available in GeoGebra. The AR camera in the GeoGebra application allows anyone to install and view AR objects that educators have built on the identified flat planes. Geogebra allows educators to create classes and collaborate with all GeoGebra users worldwide.

Based on the review results, the combination of the Unity and Vuforia applications was the most widely used, namely 62%, Assembler 9%, while the remaining 29% did not mention. In building AR, additional applications, namely Blender, are most widely used with Unity and Vuforia compared to Corel Draw, Android Studio, and Autodesk software. More detail can be seen in Figure 3.

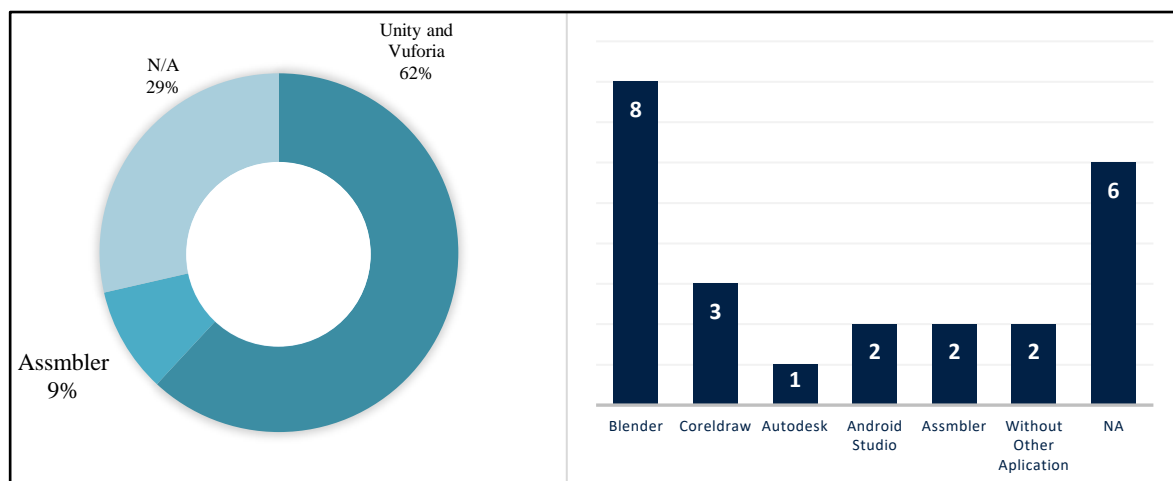


Figure 3. Distribution of AR Types and Additional Applications

RQ3: What level of education utilizes learning using AR?

The use of AR in Indonesia has reached all levels of education, from elementary to senior high school. The review results show that AR in mathematics learning in Indonesia is most widely

used at the elementary school level, with 50% of the 26 articles mentioned. This result shows that the use of AR at the high school level can still be maximized. The full results are as follows in Figure 4.

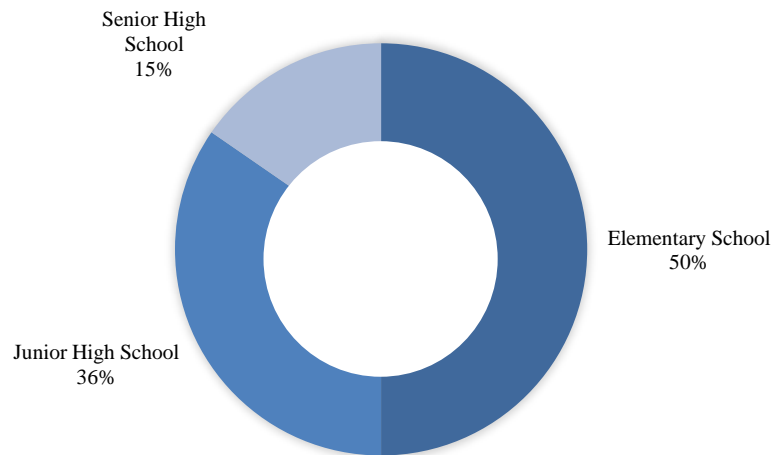


Figure 4. Distributions of Educational Level Utilizes Learning Using AR

RQ4: What type of research is used regarding AR?

The review results related to the research involving AR in learning mathematics dominantly used development research, reaching 81%. These studies produced teaching materials with various AR builders. While another 15% conducted quasi-experimental research by looking at the effectiveness of using AR, and the remaining 4% conducted classroom action research. The result is shown in Figure 5 as follows.

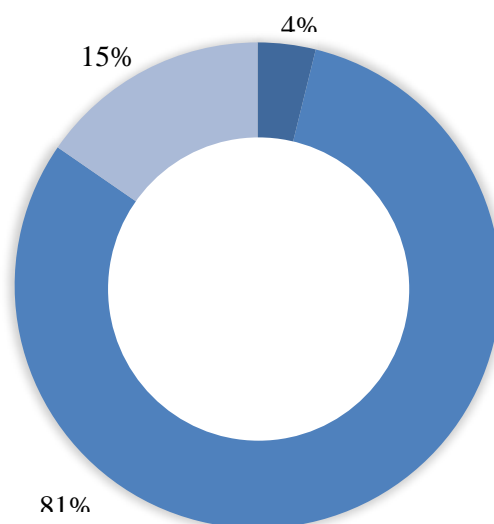


Figure 5. Distribution of Research Types Using AR

RQ5: What is the teacher's opinion about using AR in learning mathematics?

Based on the questionnaire, seven out of eight teachers agreed that the learning media needed at this time were technology-based because technology-based media can be interactive, motivate

students, create a fun learning atmosphere, and present material more concretely. Regarding the topics in mathematics that need to utilize technology, six teachers proposed material on geometry, mainly geometric shapes, while the other two proposed material on probability and numbers. Regarding mathematics learning that utilizes AR, although in general, the teachers do not know about the use of AR, after being given a presentation of the implementation in class, six teachers stated that AR-assisted learning was exciting, and two others said it was interesting.

In developing AR-assisted teaching materials, it is necessary to consider the application of the AR builder used. Research results related to AR are currently still dominantly using Unity and Vuforia software as AR-building applications. Both of these applications have advantages in terms of results, where if done by professionals, maximum results will be obtained. However, this is a challenge for educators because they must first learn how to use the two applications.

Vuforia can create and analyze flat images and simple three-dimensional objects and create geometric shapes, making them usable with the help of virtual controls. Users can rotate and zoom objects (Rashevskaya et al., 2020). The Vuforia application must be installed on a smartphone and used as a camera to recognize the target image. So that if we move the marker, the virtual object will move in sync with it. This effect gives the user the impression that a virtual model is an object that exists in the real world, even though it is not.

When looking at the convenience side, the Geogebra software can be the most accessible alternative for teachers to learn. However, many need to be made aware of Augmented Reality in GeoGebra, which is free and can be used for mathematics learning in high schools (Mailizar et al., 2020). One of the advantages of Geogebra is that the resulting geometric shapes are very precise and can be enlarged so that it is possible to see them in detail (Isharyadi & Ario, 2019). Geogebra also has a vast and highly developed community, so it has much support when teachers have difficulty developing teaching materials. Behind the ease of using GeoGebra as an AR builder, currently, from research results, only a few have published research results that utilize GeoGebra as an AR builder. Geogebra utilizes location as a digital object viewer as AR so that its use does not require a marker/target image to display AR objects. Using the Geogebra application on a smartphone, AR objects can be seen after the application identifies a flat area as a location for digital objects.

Concerning spatial thinking, Geogebra can be one of the right tools for developing AR because it has a more dynamic and interactive AR interface. With GeoGebra, students can interact directly with virtual three-dimensional objects in a dynamic geometric environment without experiencing the adverse effects of cognitive filter problems (Ozcakir & Cakiroglu, 2021). Teaching materials that will be built as a place to use AR are web-based. The web is built using Google sites which educators can use for free and easily connect with other Google ecosystems. In addition, students can visit the web anytime when a more profound understanding is needed. Teaching materials that use the web do not require storage space on the user's smartphone. The web that has been built can also be turned into an application installed on a smartphone. Therefore, Geogebra AR-assisted teaching materials will be developed in the next phase of this research.

CONCLUSIONS

Based on the results of the preliminary stages of this research project, we can draw the following conclusions. First, the use of GeoGebra as an AR builder in Indonesia still needs to be created

because Geogebra's potential is quite good. Furthermore, AR learning resources on geometry at the high school level still need to be improved. Finally, teachers agree that learning using technology has become necessary and are interested in using AR, especially in geometry. It is because AR has features to make objects dynamic, which allows students to understand the position of objects in space and how to imagine objects changing or moving, so students' spatial thinking skills can be improved. Based on these findings, the next stage is the development of teaching materials that utilize GeoGebra as an AR builder for high school geometry materials.

AUTHOR CONTRIBUTIONS STATEMENT

RI and TH were jointly involved in preparing the instruments and collecting the data. All authors collectively wrote this manuscript.

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