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AUGMENTED REALITY (AR) FOR GEOMETRY BASED ON PRIOR MATHEMATICAL KNOWLEDGE

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Abstract

This study outlined the development process of augmented reality (AR) media for teaching geometry, grounded in prior mathematical knowledge. We used the design thinking method, consisting of empathizing, defining, ideating, prototyping, and testing. The study showed that AR media developed for geometry based on prior mathematical knowledge was highly valid for being used by media and content expert validators. This is because AR media is designed according to students' prior mathematical knowledge, categorized into high, medium, and low levels, making geometry learning more effective. The impact extends to various fields of science, technology, engineering, and mathematics (STEM), introducing a new, more engaging, and enjoyable way of delivering educational content.

Keywords: Augmented reality, Geometry, Mathematics, Media, Teaching.

1. Introduction

Augmented Reality (AR) for geometry based on prior mathematical knowledge explores the integration of emerging technology AR with foundational cognitive skills and prior mathematical knowledge, which are critical for success in science, technology, engineering, and mathematics (STEM) education [1-5]. By focusing on prior mathematical knowledge, learners' existing competencies influence their ability to understand new concepts. Table 1 presents several articles discussing the use of AR in geometry learning media. The findings from these studies indicate that AR media serves as an effective solution for creating more engaging and innovative learning experiences for junior high school and improving high-level mathematical ability [6-11].

Table 1. Literature review of AR for geometry.

No.	Title	Ref.
1	Evaluating the impact of an augmented reality app on geometry learning in Kazakh secondary schools	[6]
2	The effectiveness of using augmented reality on the geometry thinking ability of junior high school students	[7]
3	Effects of augmented reality application integration with computational thinking in geometry topics	[8]
4	Augmented reality learning in mathematics education: A systematic literature review	[9]
5	The use of augmented reality to improve students' geometry concept problem-solving skills through the STEAM approach	[10]
6	Information communication technology (ICT)-based instructional software and its effectiveness in teaching high school geometry	[11]

This study investigated how AR can provide interactive, visual, and immersive experiences that enhance problem-solving and logical thinking, key components of computational thinking, as reported elsewhere [12-16]. Given the increasing reliance on technology in modern education, this study offered insights into how AR can be effectively leveraged to improve learning outcomes and better prepare students for future challenges in technology-driven fields. The research developed AR-based learning media that leverages students' prior mathematical knowledge to deepen their understanding of geometric concepts. The method used is design thinking, consisting of empathizing, defining, ideating, prototyping, and testing. The novelties of this study are: (i) personalized AR-based learning; (ii) segmented pedagogical strategy; and (iii) interactive evaluation of geometry skills.

2. Literature Review

The use of AR in geometry learning has shown significant potential in enhancing the understanding of abstract mathematical concepts. Many reports relating to AR have been well-documented [17-19]. AR allows for the visualization of three-dimensional (3D) objects in real space, providing an interactive experience that helps students understand geometric relationships and spatial transformations [20, 21]. In the context of geometry, the use of AR allows students to directly interact with geometric objects, such as planes and solids, thus facilitating a deeper understanding of these concepts [22-28].

Students' prior mathematical knowledge plays a crucial role in the learning process, as it influences how they comprehend new concepts. Understanding basic mathematical concepts, such as space and shape, heavily relies on students' prior knowledge [29-33]. Therefore, instruction that builds on students' prior mathematical knowledge can optimize their learning process, especially in geometry, which requires a profound understanding of spatial relationships and geometric shapes. In this context, AR can be tailored to meet students' varying levels of prior knowledge, offering a more personalized learning experience that aligns with their individual needs.

3. Method

We used design thinking, consisting of empathizing, defining, ideating, prototyping, and testing. In the first stage, empathize focused on understanding the needs of students with varying levels of prior mathematical knowledge through observations and interviews. Based on these insights, the problem to be addressed was how to design AR media to help students understand abstract geometry concepts according to their prior mathematical knowledge. In the ideate stage, we developed creative solutions in the form of AR media designs tailored to students' prior mathematical knowledge. The AR media prototype was developed in the next stage, enabling students to interact with 3D geometry objects. Finally, the testing stage involved prototyping with students, collecting feedback to evaluate its effectiveness and refining the design to align with their needs, thereby enhancing the learning experience.

4. Results and Discussion

AR media allows students to visualize geometric objects in three-dimensional (3D) forms [17, 18]. This capability helps students understand abstract concepts such as rotation, spatial transformations, and the relationships between planar shapes. The interactive nature of AR allows students to manipulate objects directly, facilitating their comprehension of materials. Students' prior mathematical knowledge serves as a critical element in this study. The developed AR media considers the varying abilities of students, including groups with high, medium, and low levels. This ensures that students can learn at their respective levels, thereby enhancing the effectiveness of the learning process.

Figure 1 illustrates the design process, where the workflow for developing the AR system begins with a main menu offering options such as introduction, competencies, materials, evaluation, and profile. If the materials or evaluation menu is selected, the camera will activate to scan markers. Once a marker is scanned, several material menus will appear, categorized according to the students' prior mathematical ability levels (high, medium, and low).

Figure 2 shows the augmented AR-based learning application designed. In this view, students are asked to select a category based on their prior mathematical knowledge, which is divided into three levels: low, medium, and high. The low level is designed for students with a basic foundational understanding of mathematics. The material presented in this category is simpler and focuses on basic geometric concepts, aiming to build a solid foundation. Medium level is designed for students who have an intermediate understanding of mathematics and are ready to learn more complex geometric concepts. The material includes deeper explanations and

introduces more challenging geometric topics. The high level is designed for students with advanced mathematical comprehension. The content in this category is more in-depth and advanced, focusing on higher-level geometric concepts and their complex applications**.** The evaluation menu in AR is also designed based on prior mathematical knowledge. Students are prompted to select one of three evaluation categories: low, medium, or high. There are several navigation tools available to help students optimize the display of objects. There are zoom-in (+) and zoom-out (-) buttons on the bottom right of the screen, allowing students to magnify or reduce the view for more detailed exploration. This display shows a geometry question categorized as high-level in an AR-based learning application.

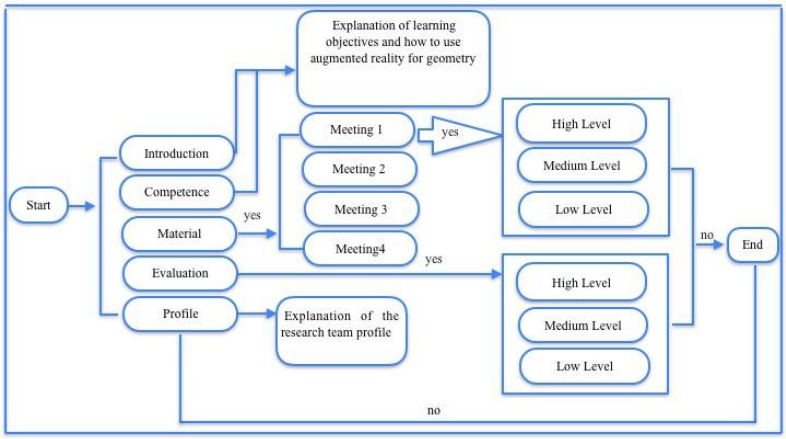

Fig. 1. Flow chart AR for geometry.

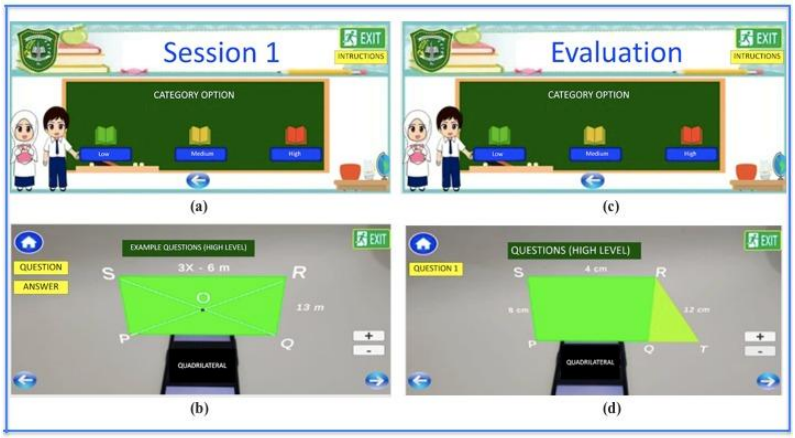

Fig. 2. Display of AR media for geometry based on prior mathematical knowledge with details: (a) material display based on meetings, (b) example question for high level, (c) evaluation display based on level, (d) example evaluation for high level.

The AR media that has been developed was then tested on several Android phones to ensure its functionality, as well as tested by media experts to evaluate the

use of visuals, text, and the relevance between the application's structure and the learning needs it is designed to address. From the testing results, the application was found to function well on several Android devices with specifications of Android version 10 and above, while the validation results from two media experts indicated a highly valid. The AR media enhances students' understanding of geometry through an interactive approach and supports technology-based learning [8-12]. The AR media is an effective tool to integrate geometry material with technology, making it relevant for use by various student generations [14-16]. The AR media for geometry has also been tested on students, the results of which show that their computational thinking skills have improved based on prior mathematical knowledge. Finally, this study adds new information in virtual laboratory as reported elsewhere [34, 35].

5. Conclusion

The conclusion of this study is the development of AR media for geometry learning based on students' prior mathematical knowledge shows very good results. The validation results from media and content experts indicate AR media is highly valid for use in geometry learning. The AR media, designed according to students' prior mathematical knowledge (high, medium, and low), enhanced their understanding of geometry concepts. This research also has a positive impact on the fields of STEM, introducing a new, more engaging, and enjoyable way to deliver educational content.

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