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PrismAR: A Mobile Augmented Reality Mathematics Card Game for Learning Prism

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Abstract: Mathematics education has benefited from the increase in popularity of augmented reality (AR) technology. However, no game-based AR application has been developed specifically for prism topic. This paper aims to report PrismAR app that we have developed. It has interactive exercises and quiz and shows the prism's edges and vertices, in 2D and 3D views. This project aims to assist primary 3 students (9 years old) in developing their mathematical abilities and making prism mathematical concepts more interactive. An exploratory study design was used to evaluate the app with 20 students from a Malaysian school. We wanted to ascertain their degree of approval for the app's design, learning content, user interface, and interactivity with the augmented reality card game teachers. Overall, the assessment returned an average mean of 4.98, which was interpreted as 'highly acceptable.' The pre-test mean result is 12.6 (S.D. = 2.012), while the post-test mean result is 14.6 (S.D. = 1.789). The results indicate that using an augmented reality-based card game could be a successful method for increasing students' mathematics competence. This study serves as a call to action for potential developers and educators to improve AR integration in math education in the future.

Keywords: Math education, E-learning, Students, Serious games, Game-based learning

1. Introduction

As the age of digital learning has evolved, augmented reality (AR) has grown in popularity. Although AR incorporate virtual objects into the real world, virtual reality incorporates a physical object into the virtual world. By overlaying digital content on top of the real world, AR will create new experiences [1]. AR is a powerful instructional technique that combines multiple instructional strategies to bolster the learning process [2]. With the rise in popularity of smart devices, the development of AR technology in daily life has accelerated dramatically. Using digital information such as graphics and sounds, AR is common for improving user experience. The growing popularity of AR applications with location awareness is a result of recent advancements in mobile technology [3].

The advancement of AR is being used in a variety of areas, including marketing, education, and gaming. A popular example of the emerging use of AR is the popular smartphone game 'Pokemon Go,' which has been downloaded by millions of people worldwide. This demonstrates that the application of AR can capture the interest of people worldwide. With the rise in popularity of mobile devices, the development of AR technology as instructional media in facilitating learning has also grown [4]. AR has the potential to transform the way we think, read, and interact. Numerous educational games are already being developed.

However, as far as we concern, no game-based AR application is being designed for the prism topic in the mathematics syllabus for standard three students in Malaysia. The prism subject requires that the prism's form be presented in three dimensions (3D). However, it can only be viewed in two dimensions (2D) via a typical textbook. As with the previous subject, students must be familiar with the sums of the corners and surfaces of each prism. As a result, the textbook's 2D visualisation makes it impossible for students to visualise the prism.

This project aims to assist primary 3 students (9 years old) in developing their mathematical abilities and making prism mathematical concepts more interactive. It is constructed using Augmented Reality (AR) technology, which enables users to interact with the educational materials. PrismAR has lessons that include learning exercises and quiz. It can show the prism's edges and vertices in both 2D and 3D views. This game involves flashcards that must be scanned with the help of the mobile application. This mobile game will assist students in visualizing the prism in three dimensions and will provide students with fun ways to learn about prisms. Additionally, it is capable of exposing students to AR games and facilitating immersive teaching

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and learning.

2. Literature Review

A. AR application in various fields

Nowadays, the widespread adoption of AR technology demonstrates that AR has established itself as a major global trend. Mobile AR applications are widely used, especially to explain scientific concepts [5]. The two types of AR are marker-based and location-based. Education, advertising, engineering, medical training, psychology, and social media are only a few examples of the areas that use AR. According to [6], in the field of education, AR has enormous potential. It facilitates an efficient and enjoyable learning process through AR game-based learning.

Besides, AR is the key to students' impact on learning in a variety of subjects and levels, regardless of their age [7]. Thus, AR is believed to be an excellent method for enhancing the delivery of education. According to [8], by incorporating AR into medical education, students gained a better understanding of the anatomical and physiological principles underlying the cardiac cycle. Additionally, AR will support students mental well-being by effectively assisting them with mathematics learning anxiety [9].

B. Enhancing learning using AR

Recently, there has been a rise in interest in augmented reality technology for educational purposes [10]. [11] describe how implementing AR can boost student's self-efficacy in learning, increase their motivation and enable them to be more receptive to higher-level ideas. A study by [12] indicates that AR can improve the learning experience by allowing students to learn by physical exploration rather than through conventional classroom instruction. [13] emphasize that incorporating augmented reality allows students to be more involved in their learning, resulting in better learning outcomes. AR aids students in developing problem-solving and higher-order reasoning abilities and can be applied in almost every subject or course. It can support students of all ages, from preschoolers to college students.

Additionally, AR is an interesting way to learn. For instance, by using AR-enabled books or cards as a marker, students can display objects in 3D through the devices they use. The use of AR in education has been shown to successfully inspire students to study. As an example, a study by [14] demonstrated how AR can be used to support, empower, and assist students, resulting in a more rapid adaptation to the laboratory setting. Students can see the object clearly with the assistance of AR, which helps them gain a better understanding of the lab equipment. Students can visualise an object better in 3D than they can with a 2D object. [15] report that AR will improve learning and can eventually replace conventional teaching-learning model.

As interactivity is a critical component of the learning process, implementing AR can provide a solution. A study by [16] demonstrates how AR technology can help students develop their ability to learn Science, Technology, Engineering, Arts, and Mathematics (STEAM) subjects. Since AR can be used in the teaching and learning process, students can comprehend and memorize information based on their experiences by using an AR application. [17] explain that game-based AR learning can be an important method of instruction because it fosters students' involvement and engagement in the learning process.

Also, research by [6] demonstrated that AR enhances the effectiveness and enjoyment of learning. The incorporation of AR technology into history education has the potential to pique students' interest in the topic. This approach is successful as the user acceptance test for the history AR game application demonstrates that it aids in the learning process. Additionally, AR can be used as a tool to replace conventional textbook-based instruction. AR has also been shown to aid in the improvement of English learning for struggling learners, according to a study conducted by [5], it aids struggling students in comprehending vocabulary, and students who participate in the use of AR technology demonstrate an increase in their performance.

Besides that, [18] indicate that AR aids in the enhancement of accomplishment and motivation when taking a Biology course. Students can gain a better understanding of cells in 3D models by using AR. Thus, it helps students to gain a greater understanding of the subject and expand their awareness to obtain higher test scores. 3D models of cells will capture students' interest, motivating them to complete the biology course. A study by [19] indicates that AR will offer a pleasurable learning environment. Students will enjoy the learning process while also improving their results. Research by [20] concluded that AR benefits students' motivation, academic success, and receptivity to a specific field of knowledge. AR implementations provide students with engaging ways to learn about a subject and supplementary knowledge. Students' concentration in class results in greater comprehension of the subject taught.

C. How AR enhances the mathematics-learning process?

Numerous topics included augmented reality technologies to help in the learning process as well. AR technology can significantly increase student satisfaction and behavior in education. In mathematics, different styles of AR implementation can be provided for better knowledge presentation. For example, a study by [21] indicates that AR can provide students with an immersive mathematics-learning environment, which can aid in their comprehension of subject concepts. Due to a large number of students in a classroom, interactive learning is not applicable. Additionally, it is inapplicable when students must revise outside class since they can only consult printed books, which have a one-way contract. Thus, interactivity is critical for optimizing the mathematics learning process.

In the geometry domain, AR can aid in the comprehension of three-dimensional structures. Via the use of AR, users can view geometry artefacts moving realistically

on mobile devices or tablets. Besides, a study by [22] suggests that AR can aid students' comprehension of three-dimensional objects from a variety of perspectives. Thus, implementing AR will offer a more graphic representation of the learning process. Students typically consult their textbooks, which contain static images of information and artefacts. However, using AR, calculations and solutions to mathematical problems can be given through animated 3D objects.

Additionally, advanced learning through AR helps to increase students' motivation to study mathematics. AR is a novel way to demonstrate mathematical solutions to pique students' interest in the topic. [23] conclude that the implementation of AR in mathematics can increase students' motivation level. Also, [24] indicate that AR can promote learning achievement. Meanwhile, AR can also increase maths proficiency for students with disabilities [25]. Since students with disabilities still struggle with mathematics, AR video modelling can provide effective and engaging ways for students to learn mathematics subjects. This approach helps them to be self-sufficient by independent learning.

D. Mobile AR platform and AR-based educational games

AR integration into a variety of different forms of games is becoming more prevalent these days. A study by [26] showed that marker-based types of AR on mobile platforms are most favoured (89% of the respondents). Several reasons to choose a mobile app include its low cost, portability, and adaptability. The mobile platform is cost-effective, and no additional equipment is needed for the implementation of AR. Mobile devices are less expensive than head-mounted display (HMD) devices.

Additionally, AR on mobile devices facilitates users' adaptation to gameplay. Mobile devices are mostly used by swiping and clicking, which consumers do daily. As a result, users can easily comprehend the instructions for using the application through mobile devices. Mobile platforms can make the application easily accessible to consumers, as the application is available through the Play Store or App Store. Installing an application on a mobile platform is significantly simpler than on HMD computers. As a result, provide users with applications that are available at any time and from any place.

Nowadays, there are several forms of AR card games available on Google Play or Apple App Store. The incorporation of AR-based card games will improve the user experience when playing the game. Two forms of AR are typically integrated into games: marker-based and location-based. Typically, a card or board is used as the marker in a marker-based AR game. In education, marker-based AR is often used. AR card games can facilitate immersive learning by allowing students to view objects in 3D through their mobile devices. A study by [27] indicates that AR is capable of enhancing the experience of using a standard flashcard through an AR application.

Also, the AR card game is compact and easy to play. The card is small, making it lightweight. Outside class, students can access knowledge and learn through the game. This broadens the learning process's circle. Students may either play the card in the AR mode when carrying their devices or play the card without carrying their devices. This provides students with a variety of learning opportunities.

Additionally, the use of augmented reality-based card games facilitates the learning process. An AR card game can act as a condensed version of a textbook. It includes simplified versions of the details found in the textbook's various topics. It offers engaging ways to learn by games rather than a traditional textbook. As a result, an enjoyable learning environment is created. Implementing AR in the educational sector has the potential to enhance the learning process. Students who have difficulty visualising three-dimensional structures and show no interest in studying may be motivated to learn by introducing an engaging and interactive approach to teaching and learning in the educational field. Numerous smartphone math apps are available on the Google Play Store. The examples are ClearBooks Geometry, ARGeo, and Geometry.

E. Existing AR mobile application for learning prism

There are numerous AR applications that cover the prism topic. However, based on a review of four currently available applications, it has some limitations. The language used in available AR applications with prism topics is one of the main limitations. None of the reviewed applications include Malay language. Because the focus of study is on Standard 3 students in Malaysia, the syllabus is written in Malay. Students are accustomed to learning the topic in Malay, so the presently available application is insufficient to assist them in learning the prism topic.

Except for the CleverBooks Geometry application, all the applications reviewed were non-paid. CleverBooks Geometry is a paid app with a free trial version that includes two markers. Five different geometry figures can be displayed using two markers. ARGeometry provides eight markers, but only four of them are geometry and the other four are cross-section figures. 3D Shapes have the most markers (13) and can display 13 geometry figures. Even though the application can display a large number of figures, it does not provide any information about the geometry figures.

In addition, the current available application also has limitations in terms of visualisation and content. Prism includes both 2D and 3D visualisation; however, some applications only include 2D or 3D visualisation. In addition, none of the applications reviewed provided any explanation for the figures displayed.Table I compares five existing AR applications that include prism content.

The waterfall model of the System Development Life Cycle (SDLC) is used to complete this project. This model is composed of five stages, the first of which is the require-

TABLE I. Comparison of existing AR application

Application	2D	3D	Content	Language
ARGeometry	Yes	Yes	4 geometry & 4 cross-section figures. There is no explanation for the figures.	English
CleverBooks Geometry	Yes	Yes	5 geometry figures. There is no explanation for the figures.	11 languages
Geometry	Yes	No	2 geometry, 1 line & 1 dot figures. There is no explanation for the figures.	English
3D Shapes AR	No	Yes	12 geometry figures. There is no explanation for the figures.	English

ment. The project's requirements are analysed. The second stage is the design phase, during which the application's interfaces and artefacts are designed following the previous phase's precise specifications. The third stage is the production phase, which is followed by the testing phase. The final step is maintenance, during which any issues that arose during the testing phase would be resolved. A waterfall model is a form of dependent SDLC in which the step that follows the previous phase depends on the previous phase. This is a one-way-cycle model. The approach for this project is depicted in Figure 1.

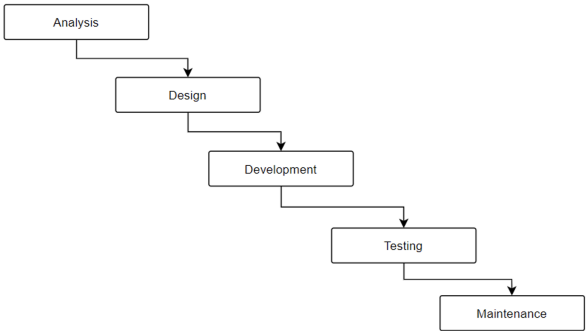

Figure 1. Waterfall Model (System Development Life Cycle)

F. Mobile Application

The use case diagram, UML class diagram, and activity diagram were designed to provide a refined view of the entire application. Figure 2 shows the use case diagram for prismAR.

When a user first launches the program, they can enter the homepage by pressing the start button. To view the prism tab, the user must first press the start button. To see the prism, the user must scan the marker after pressing the start button. The prism page will be shown if the marker is found. If the marker is already unable to be identified, the user must re-scan it. The prism's details are available on the prism website. The user will choose a different view of the detected prism, with views available in 2D or 3D, Faces, Vertexes, and Edges. The next tab is the test page. After viewing the prism, the user can access the evaluation. The user must press the test button located on the prism tab. The prism subject is covered in the test page's questions. The answers to each question are given impartially. After the user clicks the response button, the programme will display whether the answer selected is correct or incorrect.

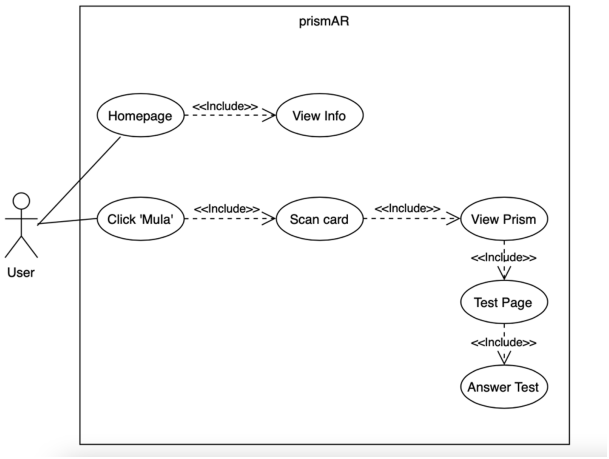

Figure 2. Use case diagram for prismAR

This application starts with the detection of the card in the detect_card class. Then, the prism will be displayed in prism_view class. The user will be able to do the test from the prism page. The test will be displayed as a class test. Figure 3 shows the full class diagram of prismAR.

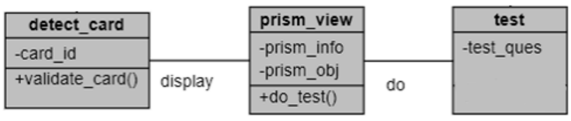

Figure 3. Full class diagram for prismAR

Figure 4 shows the activity diagram for prismAR.

The figure depicts the project's activity diagram. This project includes three activities: scanning the marker, selecting a prism monitor, and measuring. To display the prism, the user must check the marker card. The prism information will be shown after the application validates the detected marker. Users may choose to perform the test or continue displaying the prism. The prism page contains a link to the test page. Following testing, the user has the option of exiting the application or returning to the prism tab.

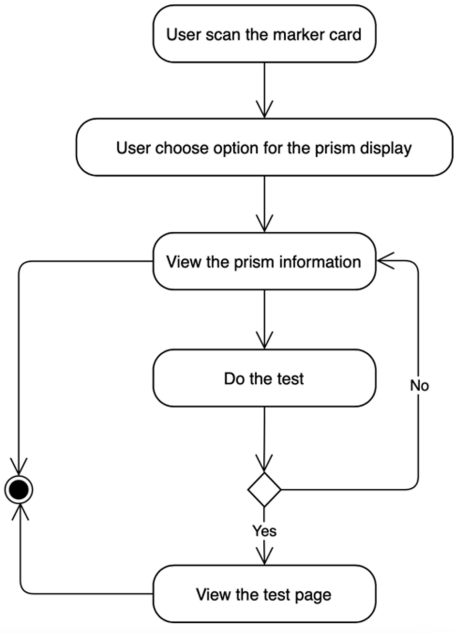

Figure 4. Activity diagram for prismAR

G. Setting

Prior to the experiment, a target school was chosen, the requisite permits obtained, and preparations made in collaboration with a math instructor.

H. Participants

This study recruited 20 students from a Malaysian school. To be included in the study, participants needed to be (1) a standard three students (9 years old) and (2) Completed the study of the Prism topic.

I. Data Collection

Quantitative data is collected in the form of pre-test, post-test, and questionnaire. An exploratory study design was used to evaluate the app with. The research exercises were designed to assist students in visualizing the abstract principles of prism. Figure 5 depicts the experimental procedure used.

The questionnaire (20 questions scored on a 5-point Likert scale) was administered to participants to assess their perceptions of the mobile applications developed. The questionnaire is based on previous research and is divided into four categories: design, learning, user interface (UI), and interactivity [28], [29], [30].

J. Analysis

In this study, descriptive analysis was used to analyse data from the data collection session. The questionnaire scores were computed in accordance with the categories. Mean and standard deviation of the scores were calculated.

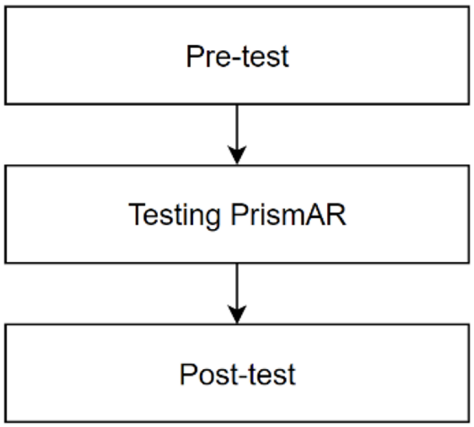

Figure 5. Experimental process

3. Result

A. Mobile Application

A mobile application prototype was developed for the testing session.

1) Development

To develop the application, Unity 3D with a Vuforia component, Adobe Photoshop CC, and Blender are used. Unity 3D is used to build the application, which includes a critical component called Vuforia that enables AR support. Adobe Photoshop CC 2018 is used to build the game cards, user interface (UI) buttons, and UI vectors. Blender is needed for designing 3D objects and animating them.

2) UI design

Meanwhile, a user-friendly user interface (UI) is needed to design this app, as the primary user will be children (standard three students). Adobe Photoshop CC was used to develop the user interface for this app.

The main page contains two buttons: 'Mula' and 'Informasi (i)'. Users can access information about the application by clicking the 'i' button. To begin, the user must click on the 'Mula' button. It will take the user to the scan tab, where the marker card must be scanned. When the marker cards that are registered with the Vuforia database detected, the prism figures will be displayed. Figure 6 illustrates prismAR introduction and scan page.

Besides, the prism page is where users can display the prism model and associated details. The detail is about the prism's faces, corners, and vertices. The page contains five distinct perspectives on the prism model. The prism can be seen in 3D, 2D, PR, 'Sisi,' or 'Bucu.' The page's 'Ujian' button directs the user to the test. The coloured box underneath the prism's name contains buttons for changing the prism's colour according to the user's preferences. When a user clicks a coloured button, the prism model

Figure 6. Home and Scan UI

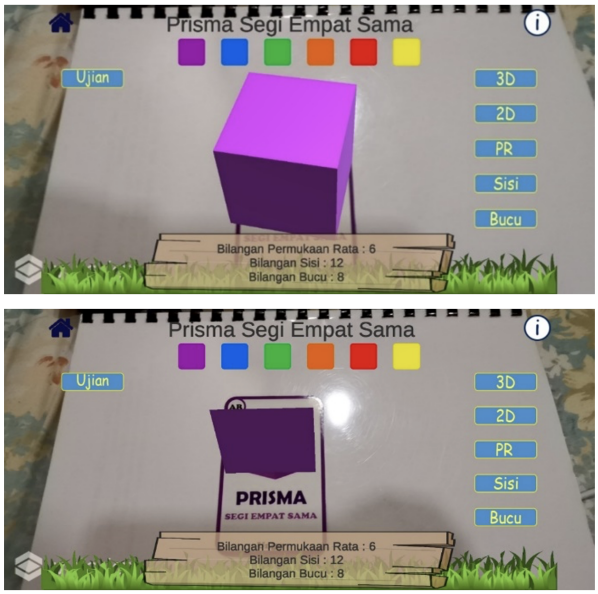

Figure 7. Prism (2D and 3D Interface

changes colour to correspond to the button clicked. The user is provided with a home button to allow them to return and select a different marker. Additionally, an Information button is given to assist users who do not understand the context of each button.

When the user clicks the 2D button, 2D geometry figure will be displayed on top of the marker card. The shape's name will appear at the top of the screen and at the bottom of the page, information about the shape will appear. On the left side of the screen, the 'Ujian' button allows users to perform the prism test. The buttons on the right side of the screen enable users to switch between different views of the geometry figures. Users can display the form in three dimensions, two dimensions, faces, edges, and vertices. Users may adjust the colour of the shape by clicking on the corresponding-coloured button underneath the shape's name. The Prism (2D and 3D) user interface is depicted in Figure 7.

When the user clicks the 'Sisi' button, the cube that was created to accentuate the card's edges would appear on top of the card. The shape's name will appear at the top of the list. When the user clicks the 'Bucu' button, the cube that was created to enhance the vertices will appear. The shape's name will also appear at the top of the list. After the user clicks the 'Ujian' button, a test question will appear. The user is presented with a prism view relevant to the topic. The question number is prominently displayed at the top of the list. Each query includes two to three response buttons. The user simply needs to click on the appropriate response to answer the questions.

B. Testing

PrismAR was tested with 20 standard 3 students to determine the design, learning, user interface, and interactivity of the AR card game (10 male, 10 Female). Prototype testing and user acceptance testing was also performed. User acceptance testing offers insight into the project's efficacy in terms of design, learning, user interface, and interactivity. A pre- and post-test are being conducted to determine the efficacy of the project prototype for studying prism topics.

1) Usability testing

This research was conducted to ascertain how the user interacts with the prototype AR game. The researcher followed users as they completed this test. Along with conducting the evaluation, the researcher observes, records, and listens to the users. This test ascertains the user satisfaction with the project prototype. The research is conducted on students in a primary 3 three school in Kota Samarahan, Sarawak, Malaysia.

2) Pre- and post-tests

A pre- and post-test were conducted to assess users' knowledge before and after the use of the prototype. The pre- and post-tests each contain twenty questions about the prism subject. Students had 30 min to complete the examination. Before the consumer using the project prototype, a pre-test is conducted. After users have used the project prototype, a post-test is conducted. Figure 8 depicts the researcher demonstrating how to use the AR game prototype to the students.

The responses of each respondent were reported and analysed. The pre-test mean result is 12.6 (S.D. = 2.012),

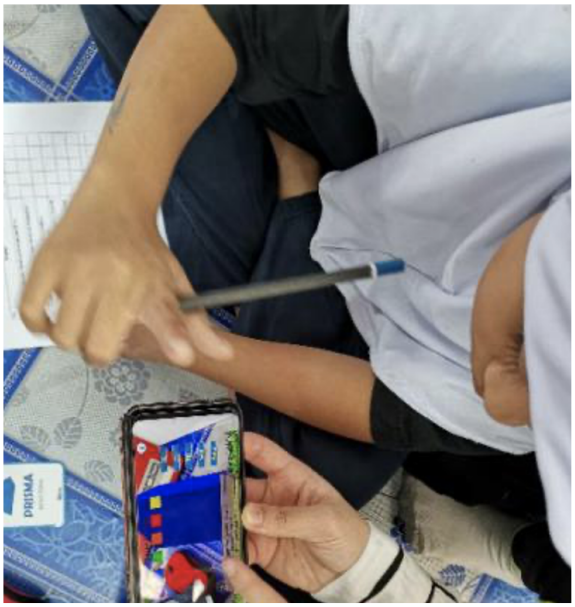

Figure 8. The researcher guiding a student on how to use prismAR

TABLE II. Pre and post-test result

N	Pre-test		Post-test	
	Mean	SD	Mean	SD
20	12.6	2.012	14.6	1.789

while the post-test mean result is 14.6 (S.D. = 1.789). The fact that the post-test mean is greater than the pre-test mean indicates that using prismAR improves students' awareness. According to the findings of the pre- and post-tests, the user's awareness of prism improved because of using the AR game prototype. The post-test mean was 2.05 higher than the pre-test mean value. The findings are summarized in Table II.

3) Interview

The interview session with a math teacher was conducted. Three types of questions were addressed. The first question focuses on the application's ability to capture students' attention. The teacher emphasises that the application is interesting, and that using it can pique the interest of students who are not interested in learning Mathematics.

"It is very interesting. Students can use the application and revise at home if they have the marker card with them. Can help students that are not interested in learning mathematics subjects."

The second question is regarding the application's content. The application, according to the teacher, provides a clear presentation of the Prism topic, and the use of 3D visualisation is immensely helpful for this topic.

"Very clear and helpful. Because prismAR can show all the edges and vertices on the device. Some students do not know what 2D and 3D are. Students could not understand where the edges and vertices are located on the prism. When using 3D, it can help students understand".

The third question concerns the use of augmented reality in the learning process. The teacher stated that the AR application is extremely beneficial and can aid in the learning process. He also mentions that AR implementation is suitable for schools because it is engaging.

"It is useful and helpful. can ease the learning process. The successful interpretation. AR is suitable to be implemented in school because it is very interesting".

4) Questionnaire

There are twenty questions, five for architecture, five for learning, five for user experience, and five for interactivity. Mean and standard deviation have been determined. The questionnaire was developed based on prior studies [28], [29], [30]. Overall, the assessment returned an average mean of 4.98, which was interpreted as 'highly acceptable.'

The results indicate that using an augmented reality-based card game format to teach prism could be a successful method for increasing students' mathematics competence. The respondents gave a perfect score for the design element (Mean = 5.00, S.D. = 0.000). Two respondents expressed their satisfaction with the project's ability to facilitate learning (Mean = 4.98, S.D. = 0.141). For user interface, the mean value is 4.97 (S.D. = 0.171). Meanwhile, the mean value for interactivity is 4.98 (S.D. = 0.141). For questions 14, 16, and 20, three respondents said that the app works well. The questionnaire includes questions on design, learning effectiveness, user interface, and interactivity. Figure 9 shows the mean for each category's questions.

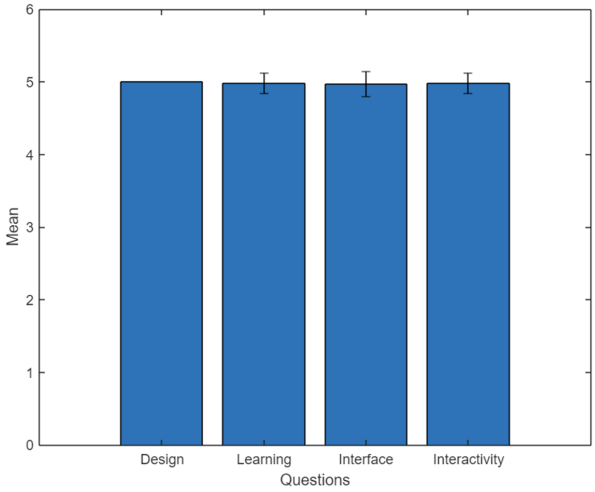

Figure 9. Result of Categorised Questionnaire (Mean and Standard Deviation)

4. Limitation

In terms of study limitation, this research was conducted with the permission of school administrators. We were limited by the students' lack of time and willingness to cooperate. We were not permitted to extend the allocated instructional time (30 min only). Bear in mind that we were needed to assess twenty students.

5. Conclusion and Future Work

In conclusion, our project has shown that it is a fun and engaging method of learning about prisms. The results indicate that using an augmented reality-based card game format to teach prism has been successful in increasing students' mathematics competence. Based on the testing and evaluation, Overall, the assessment returned an average mean of 4.98, which was interpreted as 'highly acceptable.' The pre-test mean result is 12.6 (S.D. = 2.012), while the post-test mean result is 14.6 (S.D. = 1.789).

In the future, we will enhance the marker's accuracy. The test section's use of language to include test questions also needed to be strengthened, as some users found the questions confusing. Apart from that, the app can be enhanced by incorporating animation to capture the user's attention. By including some sound effects and narration about the prism material, the app could be improved. Additionally, the 3D prism model can be enhanced by using the movement of the model without rotating the marker.

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