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Development of Augmented Reality-Based Learning Media with MDLC Model for Solid Geometry for Elementary School Students

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Abstract: Augmented Reality based media is expected to create a more interactive and engaging learning experience, enhance students' understanding, and motivate them to learn independently and actively in the digital era. The data collection stages applied include testing, observations, and the distribution of questionnaires. The development of this learning media follows the Multimedia Development Life Cycle model, which aims to design improvements to the existing system. The results of the blackbox testing, the "Bangun Ruang" application is proven to be valid and successfully used, with excellent results in the SUS test, where the Ease of Use score reached 86%, Efficiency 88%, Effectiveness 90%, and Satisfaction 87%. This indicates that the application has high levels of usability, efficiency, and effectiveness, while also providing a satisfying user experience. The application not only operates according to the designed specifications but also provides a positive user experience. Thus, it can be widely used, especially in educational environments, to help students understand geometric concepts in a more interactive and engaging way. Developers can continue maintaining and improving the application based on user feedback to ensure it remains optimal and aligned with users' needs in the future.The implementation of Augmented Reality (AR) in education can pave the way for the development of more interactive, experience-based, and adaptive learning applications tailored to students' needs. With continuously evolving technology, similar applications can be further optimized with Artificial Intelligence (AI) for content personalization, gamification to enhance learning motivation, and integration with cloud-based learning platforms to ensure broader accessibility.

Keywords: AR, Development, Geometry, Learning, Media, Solid

INTRODUCTION

In today's digital era, the use of technology in education is rapidly evolving, one of which is the implementation of Augmented Reality (AR) as an interactive learning medium. Augmented Reality allows students to understand concepts more visually and engagingly, especially in subjects that require spatial comprehension, such as geometry. The implementation of AR in geometry learning enables students to interact directly with three-dimensional geometric objects, enhancing their memory retention and conceptual understanding compared to conventional methods.

Currently, technological advancements are progressing rapidly. These developments have had a positive impact on education, marked by the emergence of various mathematics learning applications that assist teachers in delivering material, making the learning process more efficient and effective (Zalukhu et al., 2023).

Mathematics is a subject taught at every level of formal education, from elementary and secondary education to higher education. This is due to the importance of mathematics as a fundamental science that everyone must learn, considering its relevance and application in various aspects of everyday life (Putri & Pujiastuti, 2019).

Solid geometry is one of the topics in mathematics that includes various shapes and types. Each shape has formulas for area and volume, allowing us to calculate the number of faces and surface area. However, in school learning, students often struggle to visualize three-dimensional shapes realistically. The available teaching aids for solid geometry in schools are also limited in their use. Meanwhile, technological advancements have significantly progressed, including in the fields of science and education. Almost every aspect of human life now utilizes

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technology to enhance efficiency and effectiveness, one of which is through Augmented Reality (AR) (Putri & Pujiastuti, 2019)

From a teacher's perspective, geometry is still considered a difficult subject to teach. One of the main challenges is the difficulty teachers face in delivering geometry lessons due to the limited availability of teaching media (Cesaria et al., 2021). Learning media play a crucial role in supporting teachers to enhance students' thinking abilities and interest, making them more engaged in the learning process. However, teachers often struggle to create high-quality lessons, especially in mathematics. One of the key challenges is the lack of ability to present concrete illustrations of the taught material, which ultimately affects students' low academic achievement (Fatasya et al., 2023).

One of the leading innovations in information and communication technology (ICT) is Augmented Reality (AR). This technology allows the integration of the real world with digital content, creating an engaging interactive experience while providing additional visual information. This advancement opens up new opportunities for utilizing AR as an effective information medium, especially in the modern era, where access to information plays a crucial role (Fahmizher & Hartono, 2023). Augmented Reality is a technology that integrates digital content with the real world in real-time. With AR, users can see two- or three-dimensional objects projected into the real world using devices such as computers, smartphones, or specialized glasses. AR technology can be applied in various fields, including education. In education, the use of AR makes learning more effective and engaging compared to traditional methods, as it provides a broader perspective (Mubarok, 2019).

This research aims to develop AR-based learning media as an innovative solution to improve the quality of mathematics education, particularly in solid geometry topics at the elementary school level. AR-based media is expected to create a more interactive and engaging learning experience, enhance students' understanding, and motivate them to learn independently and actively in the digital era (Mubarok, 2019).

Geometry learning, especially solid geometry, is often challenging for elementary school students due to its abstract concepts and the need for strong spatial understanding. Conventional teaching methods that rely solely on textbooks and two-dimensional images are often ineffective in helping students deeply understand the shapes, structures, and characteristics of solid figures. Therefore, innovation in learning media that is more interactive and engaging, such as the use of Augmented Reality (AR), is necessary. However, there are still limitations in the development and implementation of AR-based learning media that align with the needs of elementary school students. Based on this, this study aims to formulate how the development of AR-based learning media using the Multimedia Development Life Cycle (MDLC) model can enhance students' understanding of solid geometry more effectively and enjoyably.

This study aims to develop Augmented Reality (AR)-based learning media using the Multimedia Development Life Cycle (MDLC) model to help elementary school students understand solid geometry concepts more interactively and effectively. Through the implementation of AR, this research seeks to provide a more visual and immersive learning experience, allowing students to interact directly with three-dimensional geometric objects. Additionally, this study aims to evaluate the effectiveness of the developed learning media in enhancing students' understanding of geometric concepts compared to conventional teaching methods. Thus, the results of this research are expected to contribute to technological innovation in education, particularly in mathematics learning at the elementary school level.

LITERATURE REVIEW

This research discusses the utilization of Augmented Reality (AR) technology in mathematics learning, particularly geometry. AR-based learning methods make the learning process more engaging and easier to understand compared to traditional media such as 2D books, which are less interactive. With AR, mathematical objects can be realistically displayed in an interactive 3D format and accessed through Android devices. The discussion includes definitions, characteristics, the application of AR in learning, and the design of the AR application interface. This technology is expected to enhance students' understanding, interest in learning, and create more effective geometry learning (Haratua et al., 2023).

In the era of technology, learning media based on smartphone applications are rapidly developing. Unity, as a game engine, is used to develop an Android application designed to increase the interest and understanding of eighth-grade students in junior high school regarding solid geometry. This application allows students to study materials and practice exercises. Based on a survey, 58% of users stated that the application helped their understanding, while 33% strongly agreed that the application was effective (Tuti, 2022).

This study aims to improve the activeness of mathematics learning among sixth-grade students at SD Inpres Bisara using Augmented Reality (AR) media. Conducted in two cycles with 22 students as subjects, the study showed an increase in the average learning activeness from 66% (moderate category) in the first cycle to 81.2% (high category) in the second cycle, with an increase of 14.06%. These results indicate that AR media is effective in enhancing students' learning engagement in geometry (Hairuddin, 2024).

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This research discusses the design of a virtual reality (VR) application for visualizing solid geometry by integrating Blender and Unity 3D. The background highlights the need for an innovative solution in designing more realistic solid geometry models. The development method involves creating 3D models using Blender and integrating them with Unity 3D to create an interactive VR experience. The objective of the study is to produce an effective VR-based design tool that improves conceptual understanding of architectural structures and enhances design efficiency, contributing significantly to solid geometry design (Ardhana et al., 2023).

This study aims to identify learning obstacles, design didactical plans, implement didactic activities, and assess changes after the retrospective stage. The method used is DDR (Didactical Design Research), with fifth-grade elementary school students as subjects. Data was obtained through observation. The findings indicate that students' weak visualization skills and understanding of solid geometry concepts require the use of concrete objects in teaching the concept of solid shape nets. Technological media, such as augmented reality (AR), significantly help in instilling these concepts (Niryan & Habibi, 2024).

METHOD

The Multimedia Development Life Cycle (MDLC) method is an appropriate approach for designing and developing a media application that integrates images, sound, video, animation, and other multimedia elements. The MDLC method consists of six stages: Concept, Design or Planning, Material Collection, Production, Testing, and Distribution

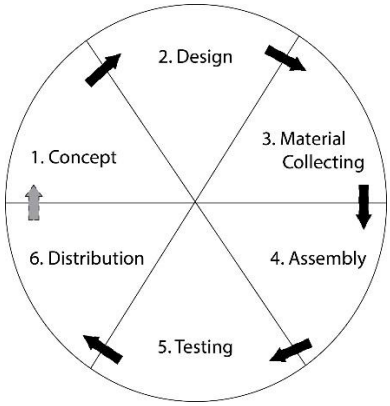

Figure 1. MDLC Method (Multimedia Development Life Cycle).

Concept

Conducting research must include structured data collection to facilitate the subsequent development stages. The concept phase aims to determine the purpose of the application, identify its target users, analyze the requirements for development, and specify the necessary hardware and software used in the application.

Design

In this phase, the software used includes Unity, Vuforia, Visual Studio Code, and Blender. This stage focuses on defining the system architecture and user interface design. The interface design outlines the application's workflow and interaction process.

Material Collecting

The material collection phase involves gathering, storing, or creating all necessary assets. It is essential to select assets that align with the pre-designed application layout to ensure consistency and functionality.

Assembly

The assembly phase involves developing the game by implementing the previously designed concept and interface. This stage includes layout arrangement, color application, and scripting. Once the game is fully assembled, it moves to the next phase.

Testing

Testing is conducted once the application is completed and ready for use to evaluate its functionality. The testing process consists of two stages: alpha testing, performed using black-box testing, and beta testing, conducted by actual users.

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Distribution

At this stage, the application has passed all testing phases successfully. The final version is distributed in file formats such as .fla, .swf, and .apk. The application is stored on Google Drive, allowing users to download it via a shared link.

RESULT

Concept

At this stage, needs identification and initial planning are carried out for the development of Augmented Reality (AR)-based learning media for solid geometry at the elementary school level. The main objective of the development is to create an interactive learning medium that helps students understand solid geometry concepts more easily through three-dimensional visualization. With AR, students can view, rotate, and zoom in on solid objects directly, making learning more engaging and effective compared to conventional methods. The target users of this media are elementary school students learning geometry, as well as teachers who can utilize it as a teaching aid.

The scope of the project includes the development of an AR-based application that displays various types of solid figures in three-dimensional form with interactive information about their properties. Additionally, the application will enable interactions such as rotation and zooming, allowing students to explore solid geometry more deeply. To support its development, the technologies and tools used include software such as Unity 3D with AR Foundation or Vuforia for AR implementation, as well as Blender or Autodesk Maya for 3D model creation. The programming languages used are C# for Unity or Java/Kotlin for mobile application development on Android/iOS platforms.

Design

Creating an application design with a storyboard is an essential step in planning the user interaction flow before the development process begins. A storyboard helps visualize the sequence of screens and application usage scenarios, making it easier for developers and designers to understand how users will interact with the available features. With a storyboard, every step in the application, from the main screen and menu navigation to the system's response to user actions, can be clearly illustrated. This not only speeds up the design process but also ensures an intuitive and efficient user experience before technical implementation takes place.

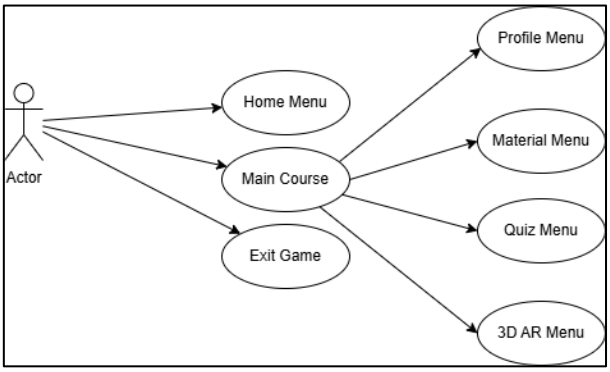

Figure 2. Use Case

The Use Case Diagram is used to illustrate the interaction between users and the system being developed, particularly in the Augmented Reality (AR)-based learning application for solid geometry. In the Design phase of the Multimedia Development Life Cycle (MDLC) model, the Use Case Diagram plays a crucial role in defining the key features and functions to be implemented in the application, such as selecting solid objects, manipulating 3D views (rotation, zooming), and presenting interactive information. This diagram provides an overview of how users, both students and teachers, will interact with the system, enabling developers to design a more efficient workflow that aligns with user needs.

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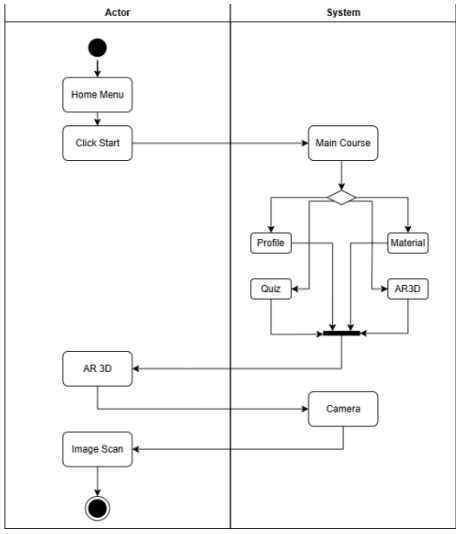

Figure 3. Activity Diagram

The displayed image is an Activity Diagram that illustrates the interaction flow between the user (actor) and the system in an Augmented Reality (AR)-based learning application. The diagram shows how the user starts from the Home Menu, then clicks Start to enter the Main Course, where several options are available, such as Profile, Material, Quiz, and AR 3D. If the user selects AR 3D, the system activates the Camera to perform an Image Scan, allowing the user to view solid geometry objects in three-dimensional form. This diagram helps visualize the application's workflow, ensuring that each step follows the designed system logic to create a more interactive and structured learning experience.

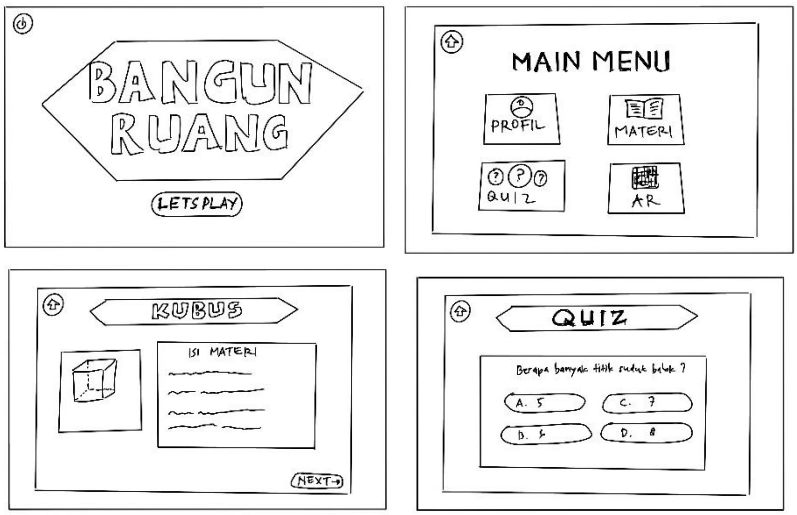

Figure 4. Storyboard

In this storyboard design, the objective is to visually represent the application flow in a structured manner, helping users understand the sequence of interactions within the 3D shape learning media application. The storyboard outlines key stages, starting from the home menu, navigating through various options such as learning materials, quizzes, and AR-based 3D object visualization. Each step in the storyboard provides a clear depiction of how users interact with the system, ensuring a seamless and engaging learning experience.

By utilizing a storyboard, developers can evaluate and refine the user experience before the actual development phase. It serves as a blueprint that highlights user actions, system responses, and interface transitions, ensuring that all essential elements are well-integrated. Additionally, this approach helps identify potential usability issues early in the design process, allowing for improvements that enhance interactivity and effectiveness in teaching solid geometry concepts through Augmented Reality (AR) technology.

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Material Collecting

In the Multimedia Development Life Cycle (MDLC), the Material Collecting phase is a crucial step in gathering all the necessary resources for developing a multimedia project, particularly in Augmented Reality (AR)-based learning. The collected learning materials include educational content on solid geometry, such as definitions, properties, volume formulas, and surface area calculations, which must align with the educational curriculum for elementary school students. Additionally, various reference sources such as textbooks, journals, and scientific articles are utilized to ensure the accuracy of the information presented in the application.

Beyond textual content, this phase also involves collecting graphic and visual media, including illustrations, diagrams, and 2D/3D animations to clarify geometric concepts. 3D models of various solid shapes are created using software such as Blender or Autodesk Maya to enhance the interactive experience in AR. Furthermore, audio sources and narrations are gathered, including voice recordings or text narrations that help students better understand the material, along with sound effects or background music to create an engaging learning atmosphere. To support application development, various software and technologies, such as Unity 3D, AR Foundation, Vuforia, and programming languages like C# or Java/Kotlin, are utilized to ensure the system runs optimally and provides an innovative learning experience.

Assembly

In the assembly stage, the coding of the "Bangun Ruang" application functions to integrate all the designed elements, such as 3D models, augmented reality markers, and the user interface, so that they can operate interactively as a complete system.

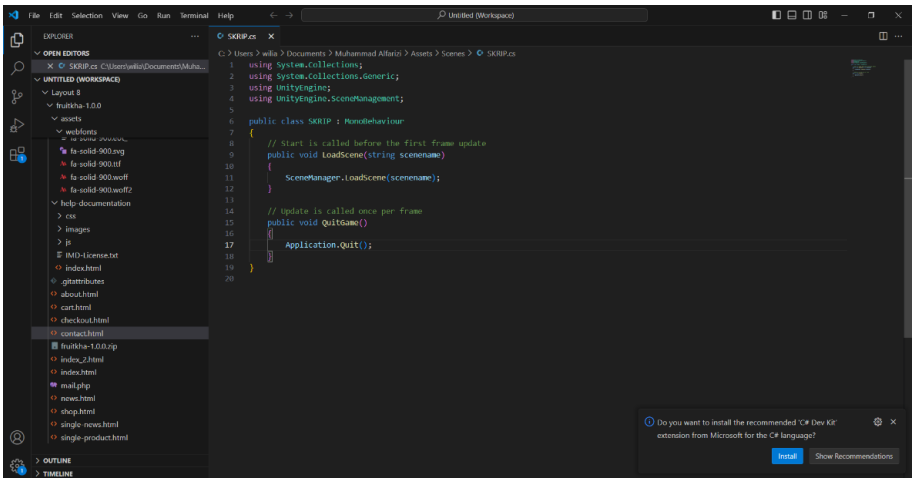

Figure 5. Codingan

Through programming using C# in Unity 3D and Vuforia SDK, the coding controls how the 3D objects of geometric shapes appear when the marker is recognized by the camera, allowing users to interact by rotating, zooming, and exploring the geometric shapes in more detail. Additionally, the coding also manages UI elements such as informational text and explanatory audio to support a more intuitive and engaging learning experience. With this stage, the "Bangun Ruang" application can be run on Android devices, providing an innovative and interactive Augmented Reality (AR)-based learning experience.

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Figure 6. Application Display

The initial interface display of an educational application themed "Bangun Ruang". The title "Bangun Ruang" indicates that the application focuses on learning three-dimensional shapes such as cubes, rectangular prisms, and others. The "Let's Play" button serves as access to start the game or available features, while the power icon in the top corner allows users to exit or close the application. The Main Menu of the educational application displays four main features visually represented in colored boxes. The "Profile" feature allows users to view information about the application's creator. The "Material" feature provides access to learning materials related to three-dimensional shapes. The "Quiz" feature is designed to test users' understanding through interactive quizzes. The "AR" (Augmented Reality) feature offers an immersive 3D visual experience for exploring geometric objects. In the top left corner, there is a Home icon to return to the initial page.

The Profile Menu serves as an information center about the application's creator. This menu is typically designed to be simple and intuitive for easy access by users from various backgrounds. The main elements displayed include a profile photo, followed by personal information such as the full name of the application's creator, and a Home icon to navigate back to the main page. The Material Menu contains educational content where students can access text or image-based materials, structured according to the learning topics. This menu is usually designed to be simple yet informative, with a Home icon to return to the main page. The Quiz Menu is designed to test students' understanding of the material they have learned. Students can select a quiz, answer questions, and view their final score upon completion. Additionally, there is an instant feedback feature that provides direct responses to help students identify mistakes and improve their understanding.

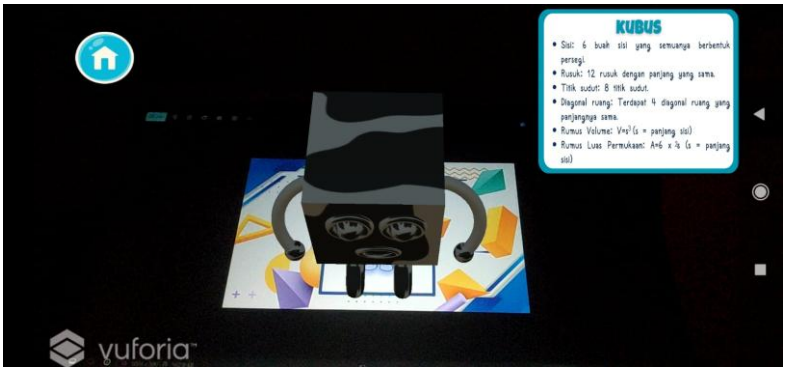

Figure 7. AR Scan Results

The AR Menu contains a key feature that utilizes Augmented Reality technology to provide a more immersive and realistic learning experience. In this menu, students can explore 3D objects, such as geometric shapes, which can be accessed through their Android devices. The AR scan results can be seen in Figure 7.

Testing

At the testing stage, testing is conducted using the Black Box Testing method to ensure that every menu and function in the "Bangun Ruang" application works as expected. This testing focuses on functionality without examining the source code, by testing each feature such as AR marker detection, 3D object display, user interaction (rotation, zoom), menu navigation, as well as quiz and learning material features. The test results are recorded in the form of test scenarios, where each feature is tested with various inputs to ensure the system responds correctly. If any errors or bugs are found, they are fixed before the application is released. With this method, the "Bangun Ruang" application is expected to provide a smooth, interactive, and technically seamless learning experience.

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Table 1. Application Testing Results

No	Menu	Testing	Result
1.	Splash Screen	The application is opened for the first time	Valid
2.	Home Menu	Users can operate the Start button and Exit button function	Valid
3.	Main Menu	Users can operate the Home, Profile, Material, Quiz and AR 3D button function	Valid
4.	Profile Menu	Users can operate the Home button function	Valid
5.	Material Menu	Users can operate the Next, Back, Home button function	Valid
6.	Quiz Menu	Users can view the Quiz Menu display, press the Answer buttons, view their score after answering all questions, operate the Quizand Home button function.	Valid
7.	AR 3D Menu	Users can view the AR scan menu display, see a short description when the marker is detected and operate the Home button function	Valid

The results of the Black Box testing on the "Bangun Ruang" application indicate that all features and functionalities have operated according to the specified requirements. Each test scenario, including input validation, page navigation, and system responses to various user actions, was successfully tested without any errors or bugs that could hinder usage. All core features function properly and provide an experience aligned with the application's development objectives. Thus, based on these testing results, the Black Box testing is declared valid, and the "Bangun Ruang" application has been successfully used by users

The testing of the "Bangun Ruang" application using the System Usability Scale (SUS) was conducted to assess the usability and user satisfaction in using the application. SUS is a standard method consisting of 10 statements that cover aspects of ease of use, efficiency, effectiveness, and overall user satisfaction. In this testing, participants were asked to provide ratings on a Likert scale, which were then calculated to obtain the application's usability score. Through this method, developers can understand how easily the application is used by users and identify obstacles they may encounter while interacting with the available features.

Table 2. SUS Testing Results

No	Aspek	Result
1.	Ease of use	86%
2.	Efficiency	88%
3.	Effectiveness	90%
4.	Statification	87%

The results of the System Usability Scale (SUS) testing with 40 respondents indicate that the application has a high level of usability. Based on the obtained results, the Ease of Use aspect scored 86%, indicating that the majority of users find the application easy to use. Meanwhile, the Efficiency aspect received a score of 88%, showing that users can complete tasks quickly and effectively. The Effectiveness aspect recorded the highest score, at 90%, indicating that the application successfully helps users achieve their goals. Additionally, the Satisfaction aspect received a score of 87%, demonstrating that users are satisfied with their experience using the application. Overall, these results confirm that the application has an excellent level of usability and provides an optimal user experience.

Distribution

At the distribution stage for the "Bangun Ruang" application, the application is distributed directly to schools so that students can use it in the learning process. Distribution is carried out through collaboration with target schools, where the application is provided in the form of an installation file or uploaded to the school's learning platform. Additionally, schools are given user guides and brief training to ensure that both teachers and students can make the most of the application. By distributing through educational institutions, the "Bangun Ruang"

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application can reach students more effectively, helping them understand geometric concepts interactively and enhancing technology-based learning experiences in the school environment

DISCUSSIONS

The results of the Black Box testing on the "Bangun Ruang" application indicate that all features and functionalities have operated according to the specified requirements. Each test scenario, including input validation, page navigation, and system responses to various user interactions, has been tested and declared successful without any bugs or errors that hinder usage.

It is concluded that all features and functionalities have operated according to the specified requirements. Each test scenario, including input validation, page navigation, and system responses to various user interactions, has been tested and declared successful without any bugs or errors that hinder usage. This indicates that the application has achieved a good level of stability and is ready to be used as an interactive Augmented Reality (AR)-based learning medium to help students better understand the concept of solid geometry.

The study by Setiawan et al. indicates that the implementation of Augmented Reality (AR) in geometry learning helps enhance students' spatial understanding more effectively than conventional methods. In this research, the development of the learning media followed the Multimedia Development Life Cycle (MDLC) stages, from concept design to application distribution. The results showed that students found it easier to comprehend the shapes and properties of solid geometry through interactive 3D visualization, which allowed them to view, rotate, and zoom in on objects directly (Rahmatika et al., 2023).

The usability aspect of using Augmented Reality (AR) for geometry learning. The developed application was tested through various evaluation methods to assess ease of use, efficiency, effectiveness, and user satisfaction. The results showed that students found the learning experience more engaging and helpful in understanding solid geometry concepts, while teachers could also utilize the application as an innovative teaching aid. Thus, these studies support the idea that the development of AR-based learning media using the MDLC model can serve as an innovative solution to enhance the quality of geometry education at the elementary school level (Maulana & Rahayu, 2020).

The application not only operates according to the designed specifications but also provides a positive user experience (Laksono et al., 2023). Thus, it can be widely used, especially in educational environments, to help students understand geometric concepts in a more interactive and engaging way. Developers can continue maintaining and improving the application based on user feedback to ensure it remains optimal and aligned with users' needs in the future

CONCLUSION

It is concluded that all features and functionalities have operated according to the specified requirements. Each test scenario, including input validation, page navigation, and system responses to various user interactions, has been tested and declared successful without any bugs or errors that hinder usage. This indicates that the application has achieved a good level of stability and is ready to be used as an interactive Augmented Reality (AR)-based learning medium to help students better understand the concept of solid geometry.

Future research can focus on the further development of Augmented Reality (AR)-based learning media using the MDLC model, with several aspects that can be improved. One promising research direction is the integration of Artificial Intelligence (AI) to adjust the difficulty level of the material based on each student's understanding and learning pace. With AI, the system can provide recommendations for additional materials or exercises tailored to individual needs, making the learning process more adaptive and personalized.

Additionally, future research can explore the use of cloud-based technology to enable broader and more collaborative access to the application. The implementation of multiplayer features or group-based learning within the AR environment could be an exciting innovation to enhance student interaction and enrich the learning experience. Further trials with a larger number of respondents from diverse educational backgrounds are also needed to evaluate the application's effectiveness more comprehensively. Thus, future research is expected to further refine AR technology in education and create a broader impact on digital learning.

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