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Implementation of Augmented Reality as an Interactive Medium for Firearms Education

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Abstract: Augmented Reality (AR) has been utilized as an interactive educational tool to support safer and more effective learning about various firearms. The application was created with Unity3D and C#, and its functionality was evaluated through black box testing. Findings show that the application operates successfully on targeted devices, though some performance issues were observed, including extended loading times and occasional lag during navigation. AR visual and interactive features enable users to explore firearm components and operational procedures without exposure to real-world risks, as the use of physical firearms is not required. The inclusion of offline access further enables users to engage with the learning materials at their convenience. AR demonstrates considerable promise for improving the quality of firearm training and may be further adopted in technical instruction, military education, and the broader development of digital learning environments.

Keywords: Augmented Reality; Interactive Learning; Firearm Training; Unity3D; Black Box Testing.

1. Introduction

Firearms play a pivotal role across various domains, including national defense, law enforcement, and sport shooting. Despite their significance, knowledge about firearms often remains limited, primarily due to restricted access and inherent safety concerns [1]. There is a clear need for safer and more accessible methods to introduce the fundamental characteristics and operational principles of firearms. With the advancement of technology, digital media have become increasingly prominent in educational settings [2]. Technology-based applications offer users interactive experiences without exposing them to the actual dangers associated with firearms [3]. The development of digital learning platforms that allow users to explore different types of firearms in a secure environment emerges as a relevant and practical solution.

Several prior studies have examined the integration of technology into firearm education and military training. For instance, Muntaha and Wulandari (2023) developed a mobile application utilizing Augmented Reality (AR) to facilitate firearm learning for student military regiments [4]. Their findings indicate that AR can foster greater engagement and understanding of firearm characteristics compared to conventional instructional methods. Similarly, Da Yuan and Zakariyah (2023) introduced an educational application that combines both markerless and marker-based AR technologies, along with an API for real-time content updates [5]. Their research highlights the flexibility and adaptability of AR-based educational tools. Further research by

Rahaweman *et al.* (2023) explored the use of AR in teaching about traditional weapons from Eastern Indonesia [6]. Their work demonstrates that AR can deepen cultural and historical understanding by making learning more engaging and interactive. Anandasyah and Arifitama (2020) focused on developing a marker-based AR application for introducing modern military firearms to the general public, enabling users to access detailed information without direct contact with actual weapons [7]. The application proved effective in providing a highly visual and engaging learning experience. Irfan and Hasibuan (2024) also contributed to this field by designing an AR-based application for learning about traditional weapons from Lampung [8]. Their approach integrates 3D models into real-world environments, enriching the educational process while supporting cultural preservation. These studies underscore the substantial promise of AR technology in advancing digital learning across diverse subject areas. The present research seeks to build on this foundation by developing an AR-based application aimed at improving understanding of firearms through interactive visualization, without the risks associated with live training.

Knowledge of firearms is crucial for personnel. However, limited access and strict regulations often complicate the learning process. AR-based applications offer a practical solution by providing an interactive learning environment where users can explore the structure, mechanisms, and features of firearms without direct exposure to real weapons. The significance of this research lies in its efforts to use safe and accessible educational technology, while minimizing the risk of errors in handling and understanding firearms. By utilizing AR, learners are expected to have a more engaging and realistic educational experience, ultimately contributing to more effective training in this field.

2. Related Work

The adoption of Augmented Reality (AR) in educational settings has rapidly expanded, offering new ways to engage students and enhance understanding through interactive and visually rich experiences. Hasibuan *et al.* (2025) observed that AR technology can significantly improve user engagement, particularly in environments where spatial visualization and dynamic interaction are essential, such as museum exhibits [9]. Such advantages are equally relevant for learning about firearms, where visualizing mechanisms and safe handling procedures is crucial. Aji (2020) developed an AR-based application for military vehicle recognition using marker-based tracking [10]. His findings suggest that AR can bridge knowledge gaps by providing learners with direct, interactive exposure to complex objects, which would otherwise be difficult to access. The approach used for military vehicles can be extended to firearms education, enabling students to examine weapon structures, operational methods, and safety protocols in three dimensions, thus supporting a more practical grasp of the subject.

Rachim *et al.* (2024) emphasized the role of AR in activating student participation and making abstract concepts more tangible [11]. By embedding digital information into physical environments, AR facilitates experiential learning, which is especially beneficial in the study of firearms. Students are able to observe the functionality of different weapon types firsthand, fostering a more intuitive understanding of their operation and safety requirements. This approach also helps address the challenges associated with teaching topics that are often viewed as sensitive or high-risk. Yuan and Zakariyah (2023) introduced an AR application for military weapon education that incorporates both marker-based and markerless tracking [5]. Their research demonstrates the flexibility of AR for military training, as it allows users to learn about weapons without the need for physical replicas. This form of digital access is particularly valuable in educational contexts where safety and accessibility are paramount concerns.

The potential of AR extends beyond technical training. Fadzil and Noor (2023) explored the use of AR in teaching two- and three-dimensional shapes, illustrating its versatility across different academic subjects [12]. Although their work focused on mathematics, the general principles of AR-enhanced learning—such as increased student motivation and improved spatial reasoning—are equally applicable to firearms education, particularly when addressing safety procedures and ethical considerations. Khairi *et al.* (2022) applied AR technology to the study of traditional kujang weapons, creating an interactive platform that not only teaches technical details but also incorporates cultural and historical perspectives [13]. This approach is relevant for modern firearms education, where understanding the cultural context and historical development of weaponry can enrich the learning process and encourage respect for diverse traditions. Nafiz (2024) further investigated AR as an interactive medium for traditional weapons education, utilizing Unity AR to create immersive learning experiences [14]. His work supports the notion that AR can facilitate learning by combining visual, auditory, and kinesthetic elements, making abstract or potentially hazardous topics more approachable.

Nawrat *et al.* (2016) developed a multimedia firearms training system that integrates digital simulations with practical exercises [15]. Their research highlights the effectiveness of combining AR with other digital tools to create comprehensive training programs that address both theoretical knowledge and practical skills. Such systems have the potential to reduce training costs and risks, while providing learners with immediate feedback and opportunities for repeated practice. These studies reveal that AR can enhance educational outcomes by transforming passive learning into an active, engaging process. In the context of firearms education, AR not only makes learning safer and more accessible but also supports a broader understanding of technical, safety, and cultural aspects. The evidence suggests that AR-based applications are well-suited to address the unique challenges of firearms training, offering flexible, interactive, and contextually rich learning experiences.

3. Research Method

3.1 Rapid Application Development (RAD) Method

In developing the application as an interactive medium for firearms learning, the Rapid Application Development (RAD) method was chosen. RAD is a software development methodology designed to accelerate the application creation process while maintaining flexibility in responding to changing user requirements [16]. This method emphasizes rapid iteration and repeated testing, enabling developers to quickly identify and address shortcomings in the system under development. RAD was selected for this study 541uet o its ability to facilitate a more responsive development process, especially in projects that require continuous adaptation. With this approach, developers can periodically evaluate and refine the application based on user feedback, resulting in a final product that better aligns with actual needs. Furthermore, RAD enables improved collaboration between the development team and users, as each stage in the development process can be reviewed and adjusted before the application is finalized [17].

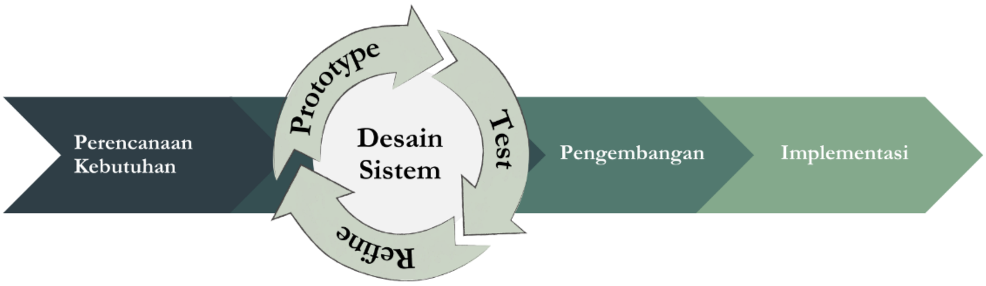

Figure 1. Rapid Application Development (RAD) Method

1) Requirement Planning
   The initial stage in implementing the RAD method involves gathering information and understanding user or client needs. At this stage, the development team engages in discussions with stakeholders to identify the primary problems the application aims to solve. Since requirements may evolve over time, flexibility in accommodating changes is crucial. Effective communication between developers and users at this stage greatly influences the application's final outcome [18].
2) System Design
   After establishing the main requirements, the next step is to design the system based on the collected information. In this phase, users are actively involved to ensure the design meets their expectations. The design process covers system structure, data management, and other core elements that will form the application. This process is dynamic, allowing improvements and refinements based on user input. The goal is to ensure the developed application meets real-world needs [18].
3) Development Process and Feedback Collection
   Once the system design is approved, developers begin building the initial version or beta of the application. This version is tested by users or clients, and their feedback is used to refine the features. The process is repeated until the application fully meets user expectations. If deficiencies or mismatches persist, developers can return to the design stage for adjustments. This approach ensures that the application is not only completed quickly but is also relevant and user-friendly [19].
4) Implementation
   The final stage in the RAD method is deploying the developed system into the operational environment. Before the official release, a series of tests are conducted to ensure the system operates correctly and is free from errors. If any issues or bugs are found during testing, developers will promptly make corrections to prepare the application for use. With this approach, the application continues to improve and adapt, ultimately functioning optimally according to user needs [19].

3.2 Research Framework

In this study, it was identified that learning firearms using 2D images has several drawbacks. Learning with static images can cause students to become disengaged and may hinder comprehensive understanding of firearm details. Additionally, limited physical access to firearms is a challenge, making it difficult for students to recognize the forms, advantages, and disadvantages of each weapon type. Therefore, this research proposes the development of an Augmented Reality (AR)-based application as a solution to enhance learning effectiveness. The application development follows two main stages. The first stage involves collecting assets related to firearms, including 3D models, technical information, and key features of each weapon type. This data serves as the foundation for developing an application that provides accurate and complete information. The second stage involves designing the AR-based firearm introduction application. With this technology, students can interact with weapon models virtually, view them from various angles, and more easily understand their characteristics.

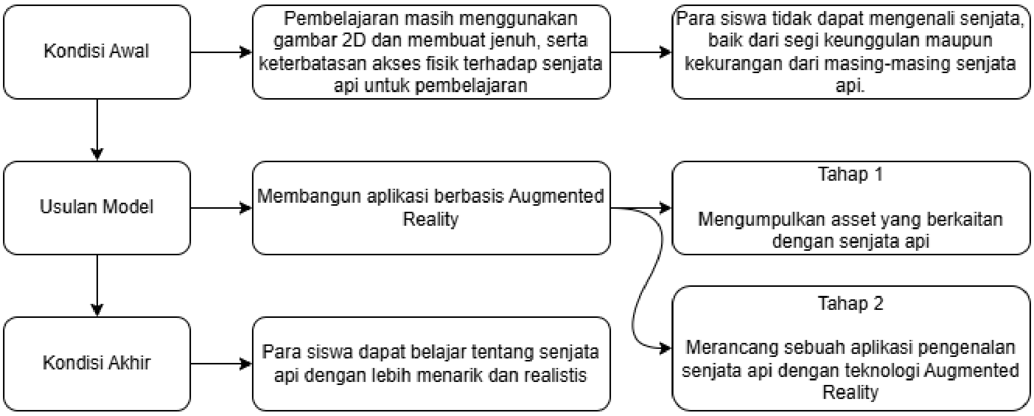

Figure 2. Research Framework

3.3 Data Collection

The data in this research is qualitative, consisting of words, statements, and images to present objects in 3D form. The data sources are secondary data obtained from previous studies. Data collection was conducted through two methods: online searches using search engines and literature studies from academic references. The data collected is as follows:

Table 1. Data Used

No	Data	Description
1	Image	AK-47
2	Image	Glock 18
3	Image	M4A1

3.4 Model Architecture

The model architecture is used to represent and explain the structure and concept of the system being developed. This model not only illustrates the main components but also explains how these components interact to form a workflow that fits the requirements. With a clear model architecture, developers can better understand the system design and observe how processes proceed from start to finish.

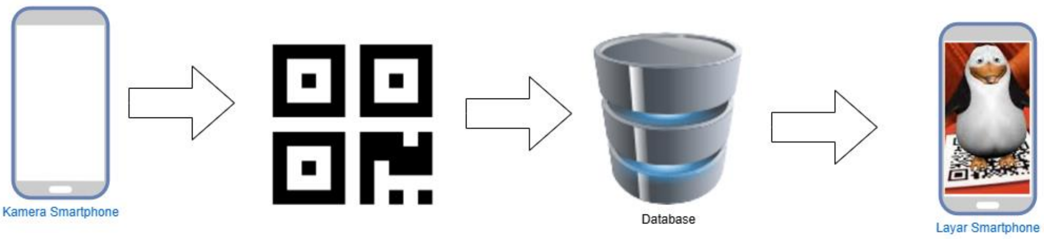

Figure 3. Model Architecture

Figure 3 above illustrates the workflow of the system designed in this research. The process begins with a smartphone camera scanning a QR code. Once the QR code is detected, the system accesses a database containing information related to the scanned object. The data retrieved from the database is then processed and displayed on the smartphone screen in visual form, such as a 3D model or related information. With this approach, users can have a more engaging and informative interactive experience.

4. Result and Discussion

4.1 Results

4.1.1 Analysis and Design

The analysis stage is carried out to determine all the requirements necessary for optimal system development. This analysis includes identifying system requirements, which are divided into two categories: functional requirements and non-functional requirements. In addition, system design aims to define the workflow and structure of the system to be built using diagrams or conceptual models for easier understanding. The functional requirements of this system include types of input, processes performed, and outputs produced. The required inputs include firearm sound data, three-dimensional firearm objects, and brief descriptions of each firearm. In the process, users must download and install the application on their smartphones, then enter the main menu. Users can access various features in the application, including activating the camera and displaying three-dimensional objects of firearms. As a final result, the system will display information about various types of firearms as well as 3D models that allow users to view their shapes more realistically. In addition to functional requirements, this system also has non-functional requirements consisting of supporting hardware and software. The hardware used is a laptop with specific specifications to ensure optimal system development. The required software includes an operating system, a game engine, image editing applications, and an SDK for augmented reality technology development. The table below summarizes the system requirements for this research:

Table 2. System Requirements

Category	Requirement Details
Input Requirements	Firearm sound data, 3D firearm objects, firearm descriptions
Process Requirements	User downloads and installs the application, accesses menu, activates camera, displays 3D objects
Output Requirements	Displays firearm information, displays 3D firearm models
Hardware	Lenovo Ideapad 5 laptop, Ryzen 7 5500U, AMD Radeon, 24GB DDR4 RAM, 500GB NVME SSD
Software	Windows 11, Unity, Picsay Pro, Vuforia SDK, Visual Studio Code

4.1.2. System Flow

The application design in this research uses a system flow diagram in the form of a flowchart. This flowchart visualizes how the system works, from the initial stage to the end, making it easier to understand the processes that occur within the application. The diagram illustrates the main steps in the system, including decisions to be made and how data moves from one process to another. The system flowchart can be seen in Figure 4 below.

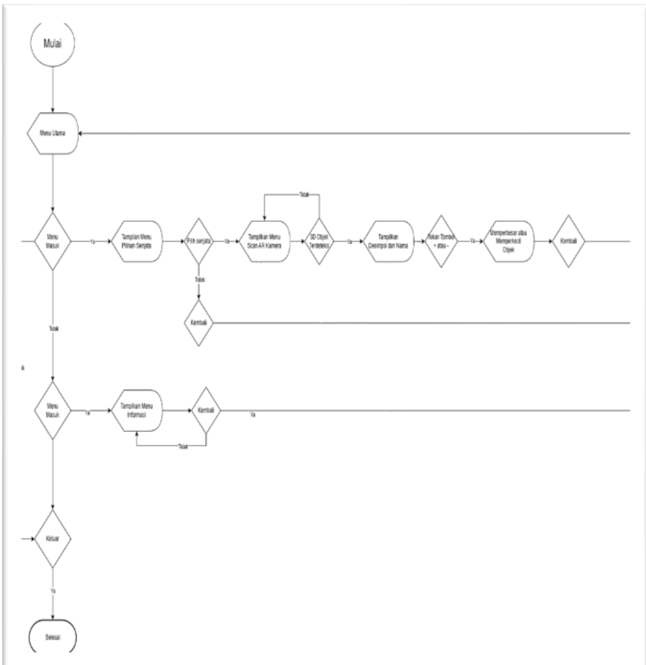

Figure 4. System Flow

In this system design, users start from the main menu, where they can choose between several options, such as entering the weapon selection menu or the information menu. If the user selects the weapon selection menu, the system will display a list of available weapons. After the user selects a weapon, the system will activate the AR Camera Scan feature. If the three-dimensional object of the firearm is successfully detected, the system will display the description and name of the weapon. In addition, users are given the option to enlarge or reduce the displayed object. If the object is not detected, the user can go back and try again. On the other hand, if the user selects the information menu, the system will display additional details about the application and its features. The user can choose to return to the main menu or exit the application. If the user chooses to exit, the system process will end.

4.1.3 Use Case Diagram

The use case diagram is used to describe the interactions between users and the system, as well as the functions available in the application. This diagram facilitates understanding of the user's role in the system and the workflow involved.

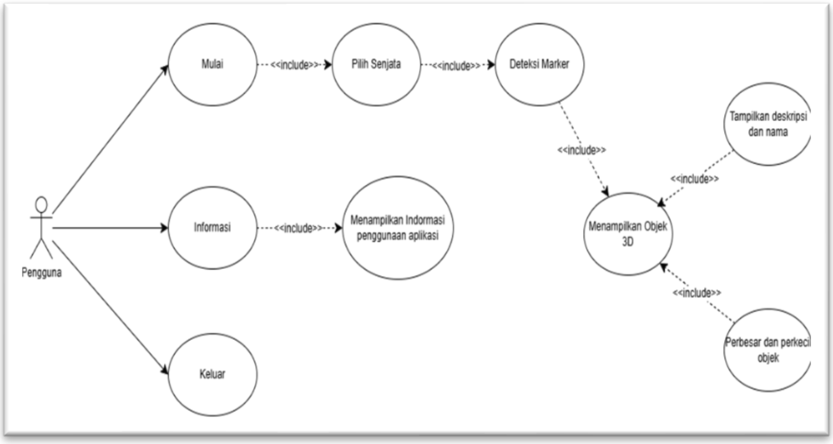

Figure 5. Use Case Diagram

In the use case diagram above, users can start the application, access information, and exit the application. When starting, users can select a weapon, then the system will perform marker detection. If successful, the system will display the 3D object, along with the description and name of the weapon, as well as the zoom in and zoom out features.

4.1.4 Activity Diagram

In this study, the activity diagram is divided into three parts. The first is the activity diagram for AR Camera Scan Marker. This diagram describes the process flow when users use the AR feature to scan a marker. The process starts with the user accessing the application, selecting the login menu, and then selecting a weapon. After that, the user points the camera at the marker, and the system detects the marker. If the marker is detected, the system will display the 3D object and its name description.

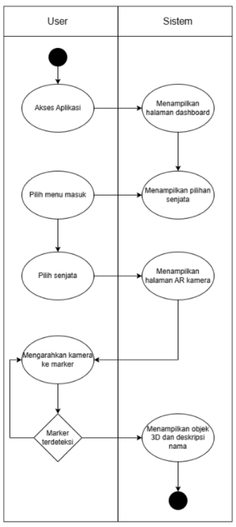

Figure 6. Activity Diagram for AR Camera Scan Marker

Next is the activity diagram for Information. This diagram describes the process of displaying the information menu in the application. The user accesses the application, and the system displays the menu page. Then, the user selects the information menu, and the system displays the desired information page.

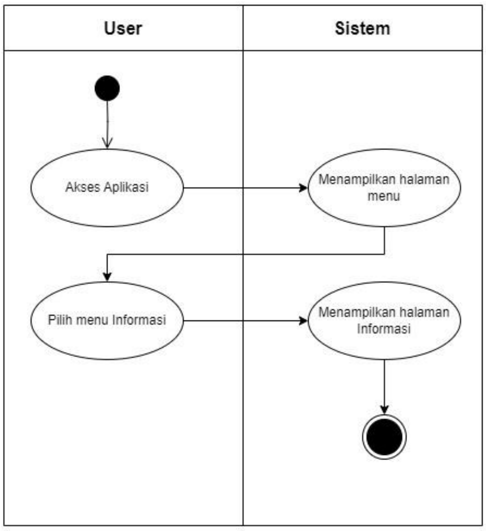

Figure 7. Activity Diagram for Information

The last is the activity diagram for Marker. This diagram explains the process of users accessing and downloading markers within the application. The user accesses the application, and the system displays the menu page. Then, the user selects the marker menu, and the system displays the page to download the marker.

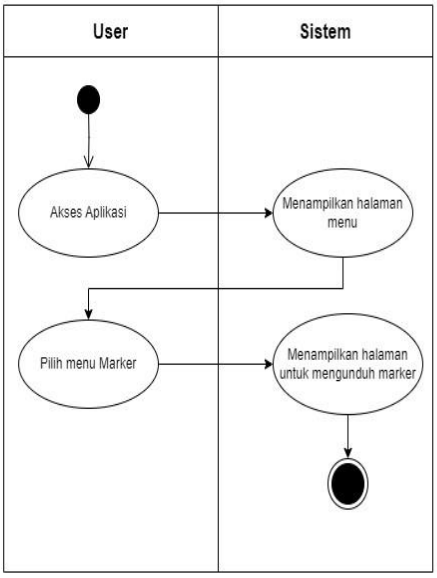

Figure 8. Activity Diagram for Marker

4.1.5 Database Design

In this study, the Vuforia SDK is used as the database to support the augmented reality (AR) feature. Vuforia SDK was chosen due to its ease of use and its capability to efficiently integrate AR technology into the application. Developers can register an account on the official Vuforia Engine website, request a license key, and manage the target markers required for the application. This process ensures that the application can accurately detect markers and display digital content in real time. For further illustration of this process, the appearance of the Vuforia Engine website can be seen in Figure 9 below.

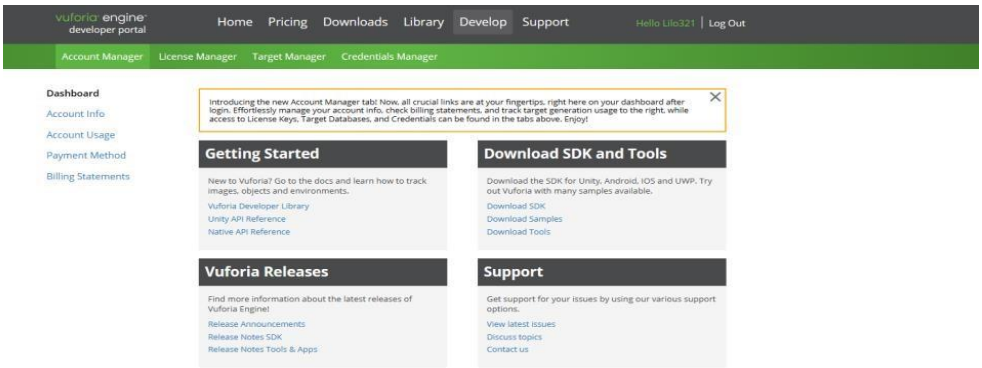

Figure 9. Vuforia Engine Website.

4.2 Discussion

4.2.1 Application Interface

The result of this research is the implementation of a system developed using the Unity3D game engine and the C# programming language. Unity3D was chosen for its capability to build interactive and augmented reality (AR)-based applications that can run on various platforms such as mobile and desktop. With Unity3D, developers can utilize a variety of features that simplify the development process, including integration with various SDKs and additional libraries. The C# programming language is used to write scripts that control system logic, user interactions, and the management of elements within the application. The use of C# in Unity is very popular because it supports flexible development, object-oriented programming, and has an easy-to-understand syntax. The results of the implemented system can be seen in the images below [5][4].

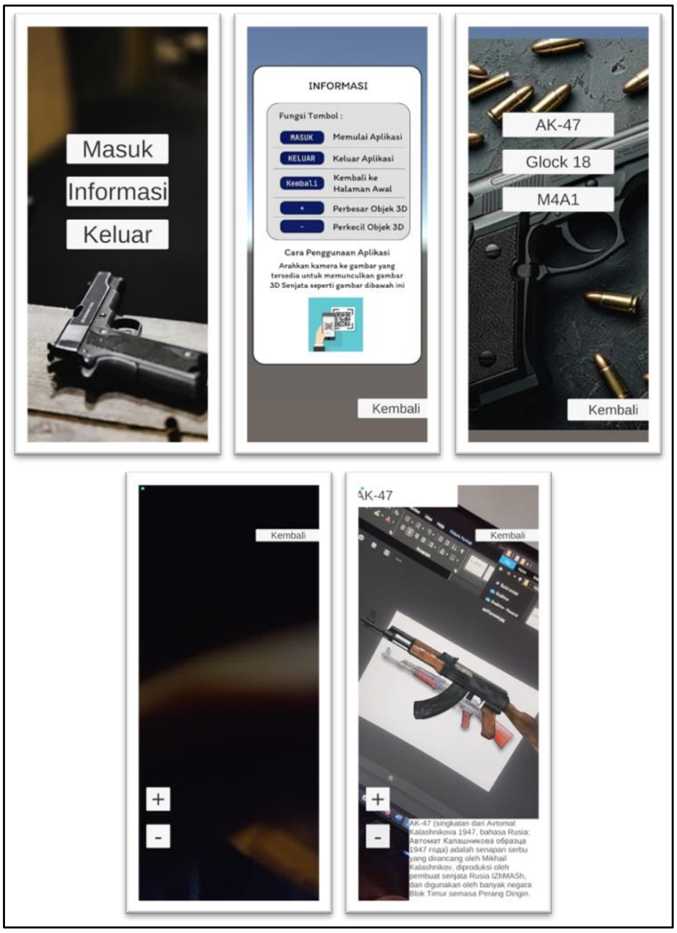

Figure 10. Application Interface

Figure 10 above shows that when users open the application, the first screen to appear is the main menu page. This page contains several navigation options that allow users to log in, view information, or exit the application. Next, there is an information menu that provides guidance regarding the function of each button and instructions on how to use the application. Users can understand how to operate the application, including how to scan markers to display 3D objects. The application also provides a login menu that contains a list of available firearms. Users can select the firearm they wish to view in the form of a 3D model. After selecting a firearm, users can access the scanner menu, where the AR camera will be activated to scan the marker. If the scanned marker matches, the system will display the three-dimensional object of the selected firearm. Additionally, there are buttons to zoom in or zoom out on the object display to provide a better interactive experience.

4.2.2 Black Box Testing

The discussion of this research includes the system testing phase, which was carried out using the black box testing method. This method is used to evaluate whether the software functions according to the functional requirements without examining the internal structure or source code. This testing focuses on the input provided and the output produced to ensure that the system works as expected. In this testing phase, several devices were used to ensure that the application can run well on various hardware specifications. The following table presents the list of devices used along with their specifications:

Table 3. Testing Devices

No	Device	Device Specifications	Status	Information
1	Samsung A20s	Android 9.0 (Pie), 32GB storage, 3GB RAM, 720 x 1560 pixels	Success	The application runs smoothly with no issues when switching between pages.
2	Infinix Hot 50 4G	Android 14, 128GB storage, 6GB RAM, 1080 x 2460 pixels	Success	The application runs smoothly with no issues when switching between pages.
3	Xiaomi Poco M4 Pro	Android 11, 128GB storage, 6GB RAM, 1080 x 2400 pixels	Success	The application runs smoothly with no issues when switching between pages.
4	Samsung Galaxy J7 Prime	Android 6.0.1 (Marshmallow), 16GB storage, 3GB RAM, 1080 x 1920 pixels	Success	The application was successfully installed and can run on the device, but the opening process takes longer than usual. Additionally, there is some lag when switching between pages, which may affect user experience.

Black box testing is generally performed at the final stage of software development to identify errors in the output as well as assess the accuracy, responsiveness, and stability of the system in various usage scenarios. With this approach, testers can evaluate whether the application has met the expected standards. In this research, black box testing was performed on various aspects of the developed application. Each input was tested to ensure that the output produced matched expectations. The test results are presented in the following table, which shows several test scenarios, the results obtained, and an assessment of the functions within the application. The application of black box testing in AR-based educational applications is a standard method to ensure that all functionalities work as intended and provide a smooth user experience across different devices [11][12].

Table 4. Black Box Testing Results

Test Scenario	Test Action	Expected Result	Test Result
Login button	Pressing the button	Opens the page for marker scanning	Success
Information button	Pressing the button	Displays the application usage information page	Success
Firearm button	Pressing the button	Displays the scanner page	Success
Home (Back) button	Pressing the button	Returns to the main menu	Success
Exit button	Pressing the button	Closes the application	Success
Scanning AK-47 marker	Pointing the AR camera at the AK-47 marker	Marker detected and displays 3D AK-47 object	Success
Scanning Glock 18 marker	Pointing the AR camera at the Glock 18 marker	Marker detected and displays 3D Glock 18 object	Success
Scanning M4A1 marker	Pointing the AR camera at the M4A1 marker	Marker detected and displays 3D M4A1 object	Success

5. Conclusion

Compared to traditional methods, augmented reality (AR) significantly enhances the firearms learning process by increasing interactivity. AR guides users through digital models, explaining the structure and operation of firearms, as well as other related processes. Most importantly, AR allows learners to engage with the material more actively, leading to practical mastery of the subject. The absence of real firearms in AR also enhances learning without creating additional safety risks, allowing users to concentrate on the content without worrying about their safety. Users have more freedom to plan their learning activities because the application is offline, allowing learning without the constraints of an internet connection. This makes this technology suitable for both formal classes and independent study sessions. While AR cannot replace real-life interaction with physical training equipment, it can be beneficial when combined with other materials, especially when physical access is limited or safety is a concern. The use of AR can also broaden the imagination of educators and trainers in other disciplines, expanding the possibilities of integrating the technology into conventional teaching frameworks as self-motivated educational exercises and simulations. The use of AR in firearms teaching provides a more effective and targeted interaction with challenging, complex, interactive, and guided content. The use of AR can transform the teaching of technical subjects, as it broadens the user base and changes the level of engagement.

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