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RESEARCH ARTICLE

Augmented Reality-Based Interactive Educational Media for Light Fire Extinguisher Training and Enhanced Emergency Preparedness

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This article contributes to:

ABSTRACT

Fire hazards are an inherent risk in every building, making it essential to understand the proper use of fire extinguishers to effectively respond, prevent the spread of fire, and minimize property damage and casualties. However, current fire extinguisher instructions are often inadequate, relying on verbal explanations or static images that are difficult to visualize. The lack of practical training due to limited facilities also results in insufficient user experience. This research aims to develop Augmented Reality (AR)-based interactive educational media to improve user understanding of light fire extinguisher training and enhance emergency preparedness. The development follows the Multimedia Development Life Cycle (MDLC) method, consisting of six stages: concept, design, material collection, assembly, testing, and distribution. The results indicate that the educational media is both highly valid and practical. Its validity is supported by the visual display, educational content, and interactivity, while its practicality is demonstrated through ease of use, time efficiency, engagement, and overall benefits. This AR-based educational media provides an innovative solution to enhance fire safety literacy and facilitate interactive learning, particularly at Universitas Negeri Padang and the broader community.

KEYWORDS

Educational media; light fire extinguisher; mobile augmented reality; MDLC

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1. INTRODUCTION

Fire hazards are inherent in all buildings and can have severe physiological and psychological consequences [1]. These risks pose significant threats to property, human safety, and well-being,

highlighting the importance of fire prevention strategies throughout a building's entire lifecycle—from design to post-construction maintenance. Effective fire management requires the early integration of safety measures, ensuring that fire protection strategies are embedded in the construction process and consistently maintained over time [2].

Electrical malfunctions, particularly short circuits, significantly contribute to building fires that can result in explosions and catastrophic damage [3]. Electrical systems present considerable fire hazards when poorly designed, improperly installed, or inadequately maintained. Common issues, such as circuit overloads, faulty wiring, and aging infrastructure, substantially increase the risk of electrical fires, which can rapidly spread to combustible materials. Given the extensive use of electrical devices in modern buildings, it is crucial to address these risks with stringent fire safety measures during the construction and operational phases [4].

Fire management encompasses more than just installing fire protection systems; it involves implementing preventative measures to reduce risk. Effective fire management includes properly selecting, maintaining, and performing suppression systems tailored to the building's specific characteristics, such as material composition, temperature conditions, airflow, and spatial configuration [5], [6]. These variables determine a building's capacity to withstand fire-related threats, especially in confined or isolated spaces.

In addition to structural measures, fire management demands proactive communication and education. Ensuring that building occupants—whether staff, students, or residents—are well-versed in fire safety practices is vital. Such education should address preventive techniques and the correct operation of fire safety equipment, including extinguishers [7]. Regular fire drills and targeted training programs are essential, particularly in high-risk environments such as university campuses. At institutions like Universitas Negeri Padang (UNP), where some older buildings heighten fire risks, combining infrastructure improvements with comprehensive fire safety education is crucial for minimizing fire-related incidents and ensuring rapid, effective emergency responses.

A clear example of the potential fire risks on campus is the fire at the Faculty of Sports Science (FIK) Mess building at UNP on November 4, 2023. The fire was reportedly triggered by an electrical short circuit, resulting in an explosion. This incident caused significant damage, destroying four of the eight rooms on the second floor and leading to an estimated total loss of one billion rupiah [8], [9]. This incident underscores the importance of enhancing fire safety training, as the lack of knowledge and hands-on experience significantly compromised the effectiveness of fire protection equipment.

One critical tool in fire safety is the light fire extinguisher, known as APAR (Alat Pemadam Api Ringan) in Indonesia. These devices are designed to tackle fires in their early stages, preventing further spread before significant damage occurs [6]. As mandatory safety equipment in workplaces and public spaces [10], fire extinguishers are essential in protecting lives and property [11].

Based on a needs survey conducted through Google Forms involving 120 respondents from the academic community, particularly students at the Faculty of Engineering UNP, significant shortcomings were identified in the understanding and skills related to the use of light fire extinguishers. The survey results revealed that 68% of respondents, equivalent to approximately 82 individuals, had a relatively good understanding of the classification of fires that could be extinguished with fire extinguishers. However, only 49% of respondents, around 59 individuals, understood the operational procedures for using fire extinguishers.

Additionally, 81% of respondents, or approximately 97 individuals, indicated that they had never participated in formal training on fire extinguisher usage. Furthermore, 84% of respondents, or about 101 individuals, stated that they had never used a fire extinguisher in an actual situation, highlighting a significant lack of practical experience in handling fire emergencies. This lack of hands-on training is a

crucial factor contributing to the overall deficiency in fire extinguisher usage skills. Since the effectiveness of fire extinguishing relies heavily on proper usage techniques, addressing this issue requires an efficient and practical approach.

One innovative solution to bridge this gap is the use of Augmented Reality (AR) technology, which can simulate the operation of light fire extinguishers. AR enables the integration of digitally generated three-dimensional representations with real-world environments [12], offering an engaging and immersive learning experience through smartphones, tablets, or other digital devices. This technological approach has the potential to enhance the learning process and improve fire extinguisher training outcomes [13], [14], [15].

In response to the identified need for more effective fire extinguisher training, this study explores AR-based educational media's design, validity, and practicality. The following research questions (RQs) are proposed:

1) How can augmented reality-based interactive educational media for light fire extinguisher training and enhanced emergency preparedness be designed using the MDLC approach?
2) How is the validity of the augmented reality-based interactive educational media for light fire extinguisher training and emergency preparedness assessed by experts?
3) How do users evaluate the practicality and effectiveness of augmented reality-based interactive educational media for light fire extinguisher training in improving emergency preparedness?

Using AR, users can engage in an interactive simulation that provides step-by-step guidance on fire extinguishers. This approach addresses the problem of insufficient instructional material for using fire extinguishers. Therefore, the application of augmented reality-based fire extinguisher educational media can effectively overcome this challenge, offering practical, interactive, and easily accessible training for the academic community on campus.

2. METHODS

The Multimedia Development Life Cycle (MDLC) method was adopted in this study due to its structured and systematic approach to multimedia-based application development. This method is widely used in educational technology development as it ensures seamless integration of multimedia components and an optimized user experience. MDLC consists of six key stages: concept, design, material collection, assembly, testing, and distribution [16], as shown in Figure 1. Each stage is essential in ensuring the successful development and implementation of the Augmented Reality (AR)-based interactive educational media for fire extinguisher training.

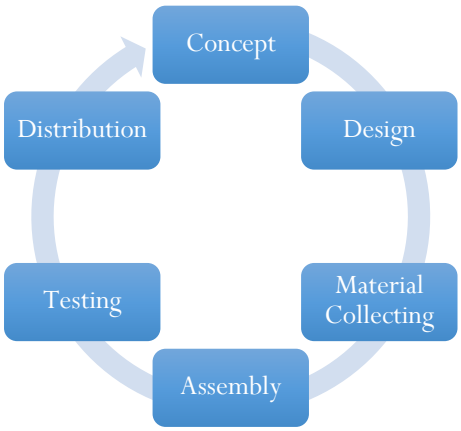

Figure 1. MDLC Development Methods

2.1. Concept Stage

The concept stage is the foundation of the multimedia development process, focusing on defining the project's objectives, target users, and the core functionalities of the application. This study addresses the lack of effective training tools for fire extinguisher usage, particularly among students and the academic community. Traditional fire extinguisher instruction methods are often text-heavy, lack interactivity, and fail to provide a hands-on experience, especially in emergency situations.

To overcome these limitations, this study proposes the development of an interactive AR-based educational application that enables users to engage with 3D simulations of fire extinguishers. The application is designed to provide realistic visualizations of fire classification, extinguisher types, and proper operating procedures. Users can interactively practice fire extinguisher operations through AR simulations, ensuring better retention and comprehension of safety procedures. Furthermore, the Android-based implementation ensures accessibility without dependence on an internet connection, making it a practical solution for fire safety preparedness.

2.1.1. Hardware, Software, and Functional Requirements

To support the development and execution of the AR-based fire extinguisher training system, hardware, software, and functional requirements were carefully selected (Table 1).

Table 1. Hardware, software, and functional requirements

Software Requirements	Hardware Requirements	Functional Requirements
Unity3D (2022.3 LTS) for app development	Android smartphones with gyroscope and ARCore support	AR marker recognition to trigger 3D fire extinguisher models
Blender 3.6 for 3D modeling and animation		
Vuforia SDK for AR functionality	Minimum 4GB RAM and Quad-core CPU for smooth rendering	Step-by-step interactive tutorials with voice instructions
Adobe Illustrator for UI/UX design		

2.2. Design Stage

The design stage is a stage to determine the shape and flow of the application to be created [17]. In this stage, a flowchart flow design is created that contains a sequence of stages, describes the visual appearance of the interface, and builds a storyboard that will show each stage. In this stage, the system's various material requirements will be met, especially in the form of design plans. The design made will be a reference for the development of educational media.

At the design stage, activity diagrams are used to illustrate the flow of the application that Shows the process and activity path. Starting from the splashscreen, head to the main menu with a choice of guides, knowledge, visualizations, profiles, or exits. The knowledge menu has sub-menus related to fire and fire extinguishers, while the visualization menu displays the parts or use of fire extinguishers. All activities end at a single endpoint marked with a red-framed black circle. This diagram is shown on Figure 2.

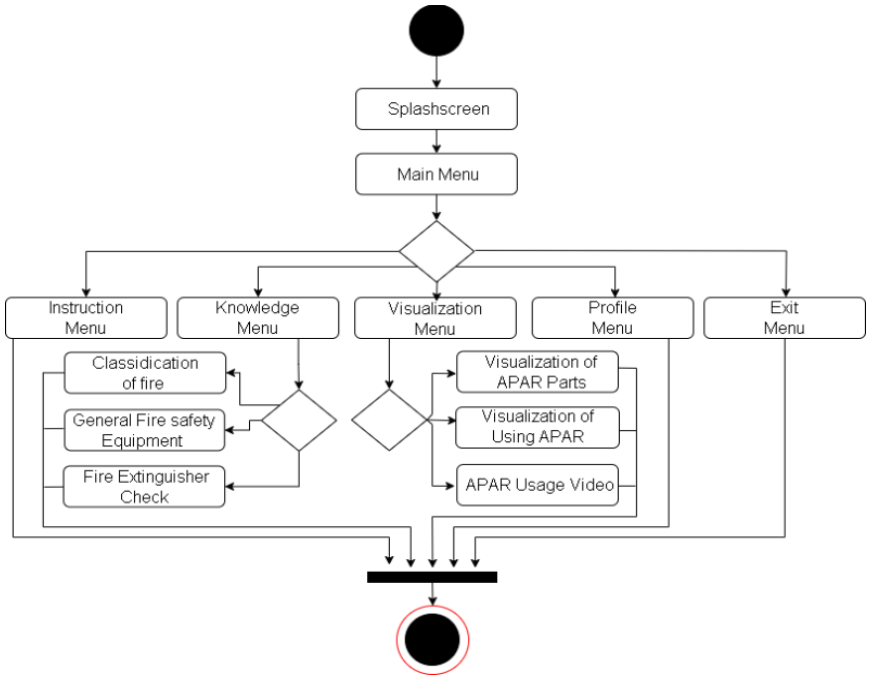

Figure 2. Activity Diagram

A significant part of the design process involves modeling the fire extinguisher components. The fire extinguisher's key parts, such as the lever, hose, and pin, were created using Blender 3.6 (Figure 3). Each AR scene was carefully detailed, including animations for fire ignition, the operation of the fire extinguisher, and the feedback provided to the user. These animations are integrated into the app's flow, ensuring users can interact with the fire extinguisher realistically and engagingly. Additionally, Table 3 outlines the specifications for the 3D models used in the educational media development:

Table 3. 3D Model Specifications

No.	Component	Description	Software Used
1	Fire Extinguisher	High-poly model with texture mapping	Blender 3.6
2	Fire Simulation	Particle-based flame animation	Unity VFX
3	AR Marker	Custom AR marker for model anchoring	Vuforia

Figure 3 shows the 3D model of the fire extinguisher created in Blender 3.6; the eight (8) main components of a fire extinguisher are clearly shown:

1) **Pressure Gauge**: Measures the internal pressure of the fire extinguisher to ensure it is ready for use.
2) **Lever**: Activates the extinguisher to release the contents when pressed.
3) **Safety Pin**: Prevents accidental discharge by securing the lever until removed.
4) **Valve**: Controls the release of the extinguishing agent from the cylinder.
5) **Cylinder Tank**: The body of the fire extinguisher that holds the extinguishing agent under pressure.
6) **Hose**: A flexible pipe that directs the extinguishing agent from the cylinder to the nozzle.
7) **Funnel Holder**: Keeps the funnel securely in place during the extinguisher's operation, ensuring the agent's accurate direction.
8) **Nozzle**: The outlet through which the extinguishing agent is directed at the fire.

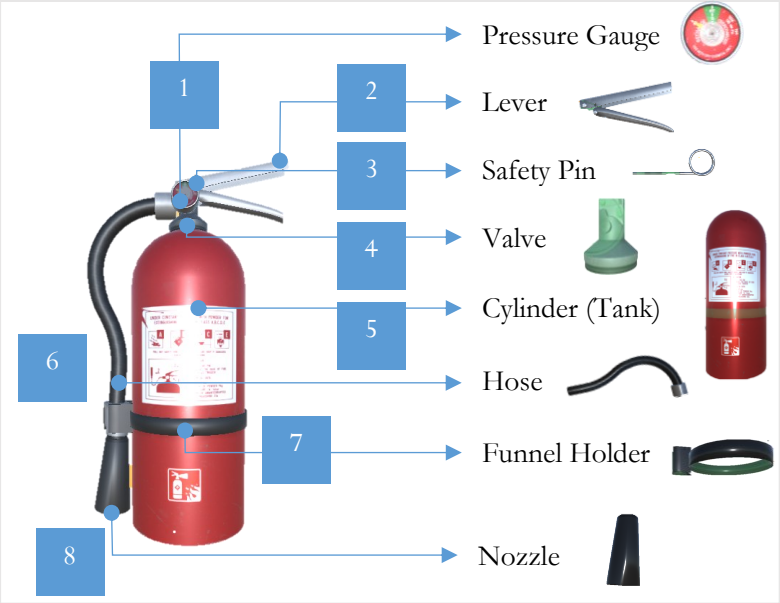

Figure 3. 3D Fire Extinguisher Model in Blender

This model includes detailed texture mapping to enhance the realism of the simulation. The fire simulation, created using Unity VFX, generates realistic flame animations, simulating fire ignition and the subsequent use of the fire extinguisher. Finally, Vuforia was used to create a custom AR marker that anchors the 3D models in the real world, enabling the interactive AR experience. This integration ensures that users can interact with the virtual fire extinguisher in a real-world setting, learning how to use it effectively in an emergency.

2.3. Material Collecting Stage

At the material collection stage, various elements necessary for designing the augmented reality-based interactive educational media for fire extinguishers are gathered. These elements include images, 3D assets, UI components, videos, audio, and text. The images include the app logo and AR markers to enable interactive visualizations. The 3D assets feature fire extinguisher components such as levers, pins, indicators, valves, hoses, and tubes to create a realistic visual experience. Button designs are developed to facilitate smooth navigation and interaction within the app. Videos are incorporated to demonstrate the practical use of fire extinguishers in real-life scenarios, while audio elements, such as background music, help foster a comfortable and engaging learning atmosphere. To ensure optimal readability, the text is carefully crafted with clear fonts and contrasting colors. Once collected, all these materials will be processed further in the assembly stage to create interactive and informative educational media.

2.3.1. Images

The collection of materials in the form of drawings required for the purposes of the design, which is detailed in Table 4.

Table 4. Marker material collection

Marker	Information
	The logo serves as a visual representation of the app, displayed when the app is running.
	The maker functions to bring up 3D visualizations of the use of fire extinguishers in the form of augmented reality
	QR codes make it easier to distribute apps by allowing users to scan to access apps or related information.

2.3.2. Button Material Collection

The collection of materials in the form of button designs to facilitate user interaction, which is required to be displayed in the AR application, can be seen in Table 5.

Table 5. Button material collection

Button	Information
	The Knowledge button serves to direct users to a knowledge center page
	The Visual button functions to interactively open the fire extinguisher visualization page
	The Profile button serves to access the user's profile page or information about the app.
	The Exit button functions to close the application and exit the system.
	The Play button is used to start or resume playback of an animation or related video.
	The Pause button works to pause an animation or video that is playing.
	The Close button is used to close the menu or pop-up window that is open.
	The Back button serves to return to the previous page or menu in the application.
	The Home button serves to direct users back to the main page of the application.
	The Reload button is used to reload content or displays that are currently active, including AR visualizations and other interactive elements

In addition to 3D object images and buttons, several components such as video, audio, and text are used in the app to improve learning effectiveness. The in-app video features a hands-on demonstration of the use of a fire extinguisher, providing practical examples that help users better understand the procedure. Audio in the form of music is used as a sound background to create a comfortable and focused atmosphere, while also reinforcing the appeal of the app. Meanwhile, the text is designed to be clear and easy to read, using contrasting fonts and colors to ensure optimal readability. The font types used include *LiberationSans SDF*, *Antonio*, and *Open Sans*.

2.4. Assembly

The assembly stage focuses on integrating the collected materials and transforming them into a functional application. This stage occurred in Unity3D, where the components, assets, and functionalities were combined to create the final application. The following key steps were involved:

1) **3D Model Integration:** The 3D models created in Blender 3.6 (such as the fire extinguisher) were exported and imported into Unity. These models were optimized for mobile rendering to ensure smooth performance on various devices. Optimization includes reducing polygon counts, adjusting textures, and ensuring the models load efficiently during the AR experience.

2) **AR Functionality:** The Vuforia SDK enabled the application's augmented reality (AR) features. The AR marker recognition system was configured to track markers and anchor the 3D models within the real-world environment. When the user scans the predefined AR marker, the 3D model of the fire extinguisher appears, and the interaction begins.

3) **Interactivity:** To make the simulation interactive, C# scripts were written to allow users to interact with the fire extinguisher. Key interactions include pulling the extinguisher's pin, aiming the hose, and simulating the operation of the fire extinguisher. These scripts were attached to the appropriate game objects, enabling responsive interactions during the AR simulation.

4) **UI/UX:** The user interface (UI) was developed to ensure that navigation through the application was smooth and intuitive. Menus, buttons, and scene transitions were implemented to guide the user through the educational process. These UI elements were linked to various scenes, ensuring that the application provided clear instructions and responsive feedback at every stage of the learning process.

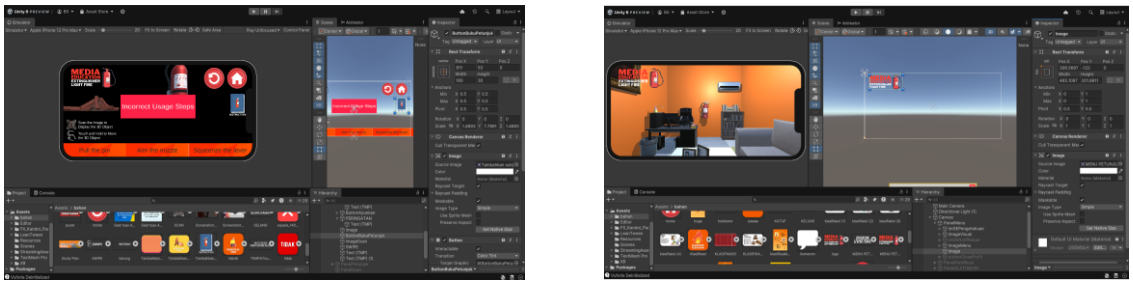

Figure 4. AR Scene Assembly in Unity

Figure 4 shows an example of the AR scene assembly in Unity3D, highlighting how the 3D models, AR functionality, and interactive elements were brought together in the final application. This stage was critical for ensuring all components functioned correctly and cohesively within the Unity environment, resulting in a fully integrated AR-based educational tool.

2.5. Testing

The testing phase was crucial in evaluating the validity and practicality of the educational media. This phase involved two main components: the expert validation test to assess the media's accuracy and content quality and the user feedback test to measure how well the application performs in real-world scenarios. Below is a detailed breakdown of the testing process (2.5.1. and 2.5.2.).

2.5.1. Media Expert Validation Test

The validity test of the augmented reality-based interactive educational media for fire extinguishers was conducted by a panel of 4 experts. These experts included two instructional designers, one augmented reality (AR) specialist, and one fire safety expert. Each expert assessed the media based on their area of expertise, focusing on aspects such as display and visualization, educational material, and media interactivity and functionality. The assessment was conducted using a Likert scale questionnaire, which included various indicators such as the effectiveness of graphic displays, clarity of educational materials, and the responsiveness of the application. The validity score was calculated using the formula (1), and the results are summarized in Table 6.

$$Validity\ Score = \frac{Total\ Scores\ Obtained}{Maximum\ Possible\ Score}\ x\ 100\% \quad (1)$$

Table 6. Validity Test Category

No.	Validation Values	Category
1	90% - 100%	Highly Valid
2	80% - 89%	Valid
3	65% - 79%	Quite Valid
4	55% - 64%	Less Valid
5	<55%	Highly Invalid

2.5.2. Media Practicality Test

The media practicality test assessed how well the educational media met the users' needs in real-world applications. In this phase, end-users were involved in providing feedback on the user-friendliness, time efficiency, attractiveness, and benefits of the media in improving the understanding and usage of fire extinguishers. Data on the application's practicality was collected using questionnaires distributed to a sample of 35 randomly selected users. The responses were analyzed to calculate the practicality score using the formula (2):

$$Practicality\ Score = \frac{Total\ Scores\ Obtained}{Maximum\ Possible\ Scores}\ x\ 100\% \quad (2)$$

After calculating the practicality score, the responses were categorized into various practicality aspects, as shown in Table 7 below, which summarizes the results [18].

Table 7. Practicality Test Category

No.	Score Interval	Category
1	86% - 100%	Very Practical
2	76% - 85%	Practical
3	60% - 75%	Quite Practical
4	55% - 59%	Less Practical
5	<55%	Impractical

2.6. Distribution

Once the application was finalized, it was packaged into an APK file and prepared for distribution. The distribution strategy focused on maximizing accessibility and ensuring users could quickly obtain the app when needed. Figure 5 shows that custom AR markers were strategically placed near fire extinguishers at key locations within Universitas Negeri Padang. Users could scan the AR marker with their devices to immediately access and launch the app, providing quick and convenient access to the Augmented Reality-based fire extinguisher training.

An important app feature is its offline functionality, allowing users to access the training without an internet connection. This feature is especially critical in emergencies, where internet access may be limited or unavailable, ensuring that users can still learn how to operate fire extinguishers effectively during a fire emergency.

Figure 5. AR Marker Placement Strategy

The AR marker distribution strategy facilitates easy and immediate access to the training, ensuring that the educational media reaches users effectively when they are near fire extinguishers, ready to learn and act in case of an emergency.

3. RESULTS

At this stage, all the elements and materials of the augmented reality-based interactive educational media for fire extinguishers that have been collected, such as 3D objects, text, images, and sounds, are combined according to the planned design. The creation process uses special software, following the storyboard, navigation flow, and application structure determined at the design stage. Each component of educational media ensures that the display, interaction, and function run well. At this stage, the AR development interaction with markers is also completed so that users can view virtual objects according

to the allowed markers. The result of this stage is the initial version of educational media that is ready to be further tested.

3.1. Application Results

The final product of this project is an augmented reality-based interactive educational media for fire extinguishers designed to help users understand how to use fire extinguishers properly. The app provides real-time AR visualizations, detailed instructional materials, and interactive simulations to ensure users can effectively learn and practice fire extinguisher operations. After completing the testing and validation stages, the app is ready for distribution, and the following sections describe the detailed interface and features of the app.

3.1.1. Main Page Display

This is the first screen that appears after the user opens the app. The Main Menu features clear and accessible navigation buttons, directing users to various features available within the app, such as the Knowledge Center, Fire Extinguisher Visualization, and Light Fire Extinguisher Operation Menu. The design is simple and functional, making it easier for users to choose the option according to their needs, as shown in Figure 6.

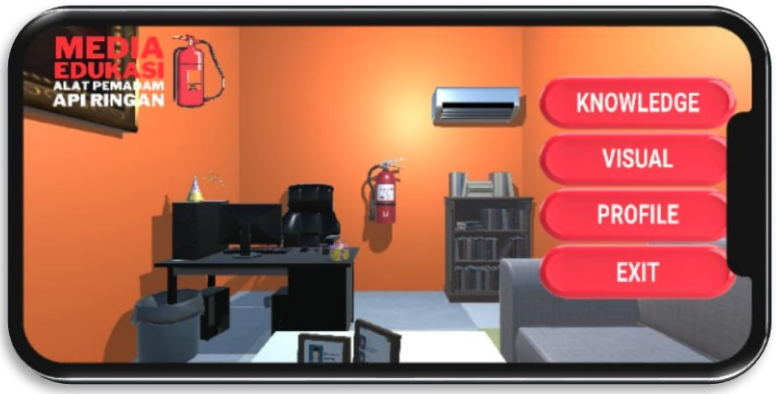

Figure 6. Main menu display

3.1.2. Knowledge Page Display

The Knowledge Menu presents comprehensive educational information about using Light Fire Extinguishers (APAR). In this menu, users can learn various materials, including fire classification, types of fire prevention equipment, and proper fire extinguisher checking procedures. The display is designed to be informative and interactive, complete with clear text, supporting illustrations, and links to additional resources that provide a deeper understanding of each topic. With this feature, users can gain broader insights into fire prevention and management, increasing their readiness to deal with emergencies effectively, as shown in Figure 7(a). The content is further detailed in Figure 7(b), showing fire classification, Figure 7(c) illustrating general fire equipment, and Figure 7(d) demonstrating the correct fire extinguisher checking technique.

(a) (b)

(c) (d)

Figure 7. (a) Knowledge page display, (b) Fire Classification Display, (c) Fire general equipment display, (d) fire extinguisher checking technique

3.1.3. Display of the Fire Extinguisher Section Visualization Page

This display explains the fire extinguisher's parts, such as tubes, hoses, levers, safety pins, cartridge indicators, hose mouthpieces, and funnel holders. Through AR visualization, users can see each fire extinguisher's component directly and understand its functions and how to use it, as shown in Figure 8.

Figure 8. Display of the visualization menu of the light fire extinguisher section

3.1.4. Display of the Fire Extinguisher Usage Visualization Page

This display allows users to interactively engage with a simulation showcasing incorrect fire extinguisher usage steps. Through Augmented Reality (AR) technology, users can visualize the errors that may occur during the operation of a fire extinguisher, such as pressing the handle or aiming

incorrectly. The simulation aims to educate users by showing them what not to do, so they can learn to avoid common mistakes in real fire emergencies. The instructional guides clearly highlight the incorrect steps, ensuring that users can understand and correct their actions, as shown in Figure 9.

Figure 9. Display of the incorrect fire extinguisher usage steps visualization

3.1.5. Light Fire Extinguisher Operation Menu Display

This menu displays an interactive guide on how to properly operate a light fire extinguisher. It provides users with step-by-step instructions on the key actions: pull the pin, aim the nozzle, and squeeze the lever. The visual interface includes an augmented reality view that allows users to interact with a 3D model of the fire extinguisher, simulating the real-life process of using the device. This functionality aims to educate users in a hands-on and engaging manner, as shown in Figure 10.

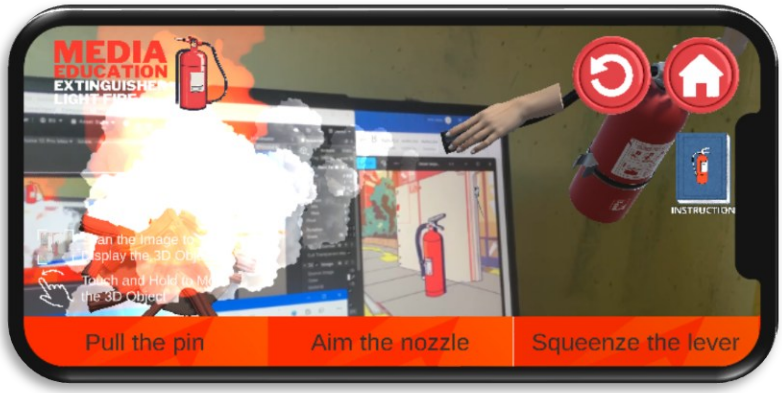

Figure 10. Interactive light fire extinguisher operation menu in augmented reality

3.1.6. Exit Page View

This page interface allows users to exit the app easily and intuitively. With a clear view and simple navigation, this page ensures that users can quickly close or exit the app after completing their activities. The design prioritizes readability, convenience, and consistency with other interface elements, providing an optimal user experience without confusion while exiting the app, as depicted in Figure 11.

Figure 11. Exit menu display

3.2. Media Validation Test

The validation test for the augmented reality-based interactive educational media for fire extinguisher training was conducted by a panel of four experts, consisting of two instructional designers, one augmented reality (AR) specialist, and one fire safety expert. The results of the validation test are summarized in Figure 12.

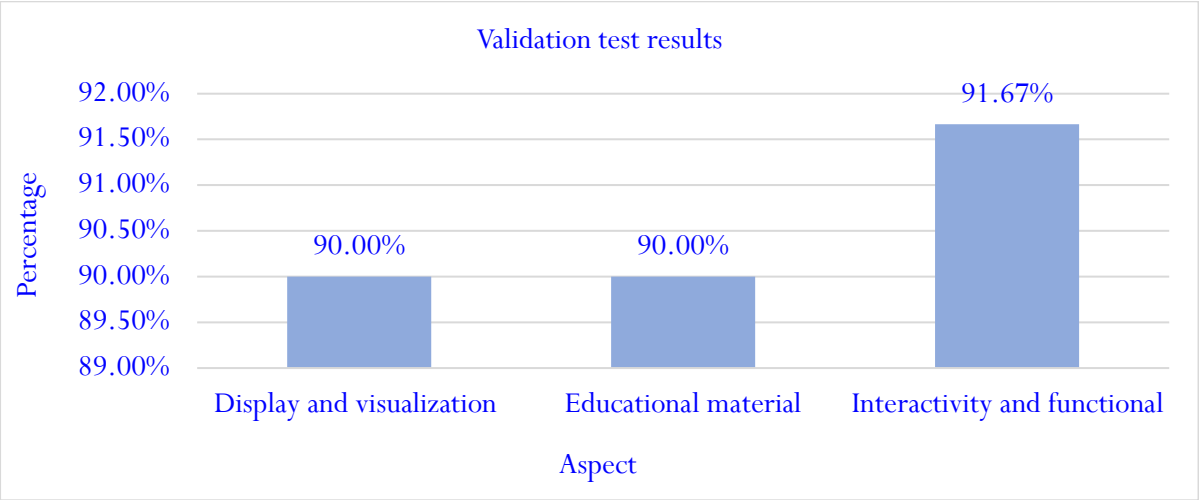

Figure 12. Validation test results

Based on Figure 12, the media validation results indicate that the visual presentation & design achieved a validity score of 90.00%, demonstrating that the 3D visualization and design meet high-quality standards. The educational content or material received an identical validity score of 90.00%, confirming that the material is relevant and effectively supports fire extinguisher training objectives. Lastly, the interactivity and functional aspects attained the highest validity score of 91.67%, highlighting the high level of user engagement and optimal system functionality. Overall, the educational media obtained an average validation score of 90.56%, classified as highly valid, making it feasible and effective for implementation in the practicality testing phase.

3.3. Practicality Test

The practicality test was conducted to evaluate the usability, efficiency, engagement, and benefits of the AR-based educational media. A total of 35 students from Universitas Negeri Padang were randomly selected as participants. The practicality test was documented in Figure 13.

Figure 13. Application usage testing documentation

Analysis of the practicality test results showed that the augmented reality-based interactive educational media for fire extinguishers received a highly positive response from participants. Most users found the application easy to use, visually engaging, and highly informative in conveying essential fire safety concepts. The results of the practicality test data are summarized in Figure 14.

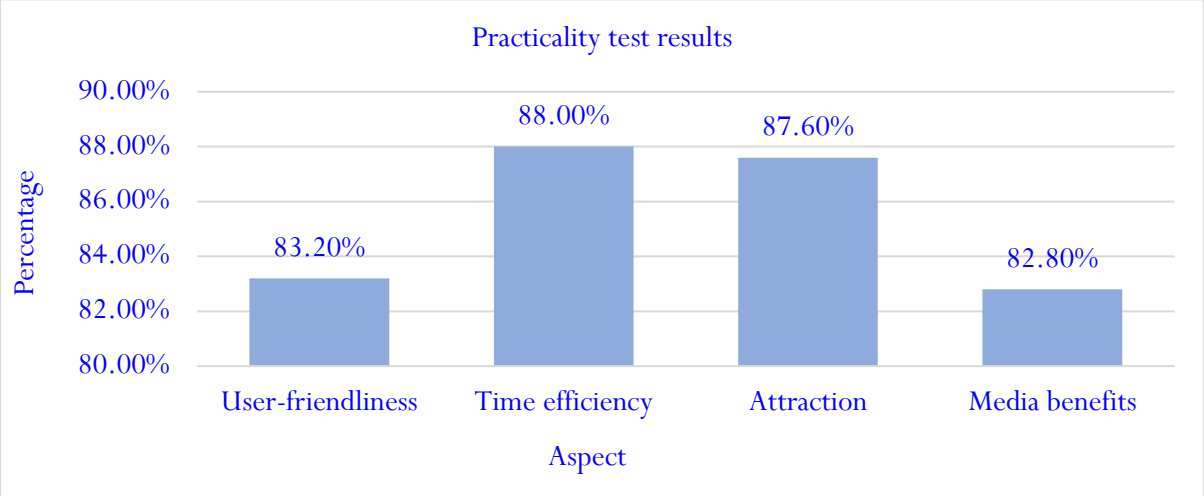

Figure 14. Practicality test results

Based on Figure 14, the results of the practicality test for the AR-based fire extinguisher training media indicate a high level of usability and effectiveness. The user-friendliness aspect received a score of 83.20%, showing that the application is intuitive and easy to navigate. In terms of time efficiency, the media achieved 88.00%, confirming that it effectively delivers content within an optimal timeframe. The visual appeal and engagement aspect scored 87.60%, indicating that the application provides a visually attractive and interactive learning experience. Additionally, the educational benefits aspect attained 82.80%, demonstrating that the media significantly enhances users' understanding and skills in fire extinguisher usage. Overall, the application achieved an average practicality score of 86.43%, classifying it as highly practical and establishing it as an effective tool for fire extinguisher training.

4. DISCUSSION

The development of augmented reality-based interactive educational media for fire extinguisher training demonstrates significant potential in enhancing fire safety preparedness at Universitas Negeri Padang (UNP). The high validity score of 90.56%, based on expert evaluation, confirms the robustness of the application's visual presentation, educational content, and interactivity. Experts emphasized the clarity of the 3D visualizations, accuracy of fire classification guidelines, and intuitive interactivity as major strengths. These findings align with previous research, highlighting AR's ability to improve procedural knowledge through immersive simulations [19], [20].

The practicality test results (86.43%) further validate the application's effectiveness in real-world scenarios. Users praised the app's ease of use, time efficiency, engaging interface, and educational benefits, leading to improved confidence and competence in operating fire extinguishers. This aligns with experiential learning theories, which emphasize interactive simulations in reinforcing muscle memory and decision-making skills under stressful conditions [21], [22], [23], [24], [25].

Moreover, the offline functionality and custom AR marker distribution strategy significantly improve accessibility, addressing the training gap identified in the initial survey, where 81% of respondents had never received formal training in fire extinguisher usage. Compared to traditional training methods, which are often theoretical, resource-intensive, or logistically constrained, AR-based simulations provide a scalable, repeatable, and cost-effective solution for institutions with limited resources.

However, several limitations were observed. The reliance on AR markers restricts training sessions to predefined locations, limiting spontaneous learning opportunities. Additionally, the application was tested only on Android devices, with no evaluation of compatibility with iOS platforms. The sample size, though statistically relevant, was limited to UNP students, raising concerns about generalizability to other demographics such as industrial workers or elderly populations. These challenges are consistent with previous AR-based learning studies, where marker dependency and platform exclusivity were identified as common barriers to adoption [26], [27], [28].

5. CONCLUSION

This study successfully developed and validated an augmented reality-based interactive educational media for fire extinguishers using the Multimedia Development Life Cycle (MDLC) framework. The application demonstrated high validity (90.56%) and strong practicality (86.43%), proving its effectiveness in bridging the gap between theoretical knowledge and hands-on fire safety training. By integrating immersive simulations, structured tutorials, and offline accessibility, this tool effectively addresses the deficiencies of traditional fire extinguisher training methods, making it a scalable and practical solution for universities and safety institutions. The implications of this research extend to educational practice, policy development, and technological adoption in fire safety training programs.

To further enhance the impact of AR-based fire safety training, future research should focus on several key areas. Expanding platform compatibility by integrating iOS and web-based AR will improve accessibility, ensuring that the training is available across different devices. Enhancing interactivity by implementing multi-user scenarios and variable fire conditions can create a more realistic emergency training experience. Conducting longitudinal studies will allow researchers to assess long-term skill retention and behavioral changes post-training, providing deeper insights into the effectiveness of the application. Additionally, testing the tool in broader contexts, such as industrial safety training and public awareness campaigns, will help evaluate its cross-sector applicability. Lastly, integrating advanced

technologies, including AI-driven adaptive learning, IoT-based hazard alerts, and markerless AR solutions, will further optimize realism and adaptability in fire safety education.

By addressing these areas, AR-based educational tools can evolve into highly effective, globally accessible fire safety training solutions, ultimately contributing to the reduction of preventable fire-related incidents worldwide.

DECLARATIONS

Author Contributions

Bima Sulistia: Conceptualization, Methodology, Investigation, Software, Data curation, Writing – Original Draft, Writing – Review & Editing. **Rizkayeni Marta:** Validation, Supervision. **Delvi Asmara:** Validation, Supervision. **David Mhlanga:** Writing – Review & Editing. **Dana Tsoy:** Writing – Review & Editing. All authors have read and approved the final version of this manuscript.

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Ethical Approval

This study was conducted following ethical guidelines for research involving human participants. A total of 35 participants, selected randomly from the student population at Universitas Negeri Padang, voluntarily participated in the practicality test of the AR-based educational media. Before participation, all participants were informed about the purpose of the study, the voluntary nature of their involvement, and the confidentiality of their responses. Informed consent was obtained from each participant before they completed the questionnaire. The study was designed to ensure that no personal information was collected or shared without consent, and all responses were anonymized to protect the participants' privacy.

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Competing Interests

The authors declare no competing interests.

Generative AI and AI-Assisted Technologies Statement

While preparing this manuscript, the author(s) used ChatGPT and Quillbot to enhance its readability, language, and overall structure. Following these tools, the author(s) performed a comprehensive review and editing process to ensure the content's accuracy, integrity, and quality. The author(s) accept full responsibility for the content and conclusions presented in this publication.

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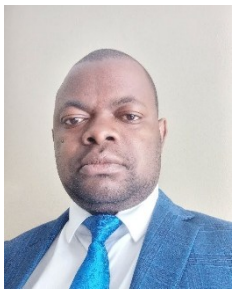

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