climbing

by Universitas Bhinneka Nusantara

SMATIKA : STIKI Informatika Jurnal
Accredited Sinta 4 Ministry of Higher Education, Science and Technology Republic of Indonesia SK No. 79/E/KPT/2023
E-ISSN: 2580-6939 || P-ISSN: 2087-0256

Mountain Climbing Safety Induction for Beginners Using Augmented Reality

Keyword

Augmented Reality; Safety Induction; Mountain Climbing; Android Application; Multimedia Learning

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Abstract

The growing popularity of mountain climbing among novice participants has been accompanied by an increased risk of accidents, largely attributable to inadequate understanding of safety procedures. Conventional safety induction methods—primarily verbal briefings and printed materials—lack interactivity and fail to adequately simulate real climbing conditions. While prior research has examined general safety education and conventional multimedia learning approaches, the application of markerless augmented reality (AR) as an interactive, mobile-based safety induction tool specifically designed for beginner mountain climbers remains underexplored . Accordingly, this study aims to develop and evaluate an Android-based markerless AR application to enhance pre-climbing safety induction for novice climbers. The application was developed following the Multimedia Development Life Cycle (MDLC), encompassing the stages of concept development, design, material collection, assembly, testing, and distribution. Functional performance was assessed using black-box testing, while feasibility was evaluated through a Likert-scale questionnaire administered to 20 beginner climbers. Black-box testing confirmed that all system functionalities operated as intended. The feasibility evaluation yielded a score of 87%, indicating a good to very good level of acceptance among users. By integrating markerless AR technology into mobile-based safety induction, this study addresses a critical gap in outdoor safety training research. The findings demonstrate the feasibility and practical potential of immersive AR applications to enhance safety awareness and improve the effectiveness of preparatory training for beginner mountain climbers.

1. Introduction

Indonesia, with its diverse natural beauty, has become a paradise for adventure tourism, and mountain climbing is one of the nature tourism activities that has experienced a significant increase in popularity in recent years [1]. This rapid growth has also been accompanied by an increase in climbing-related accidents. Between 2015 and 2019, there were 130 reported cases of missing climbers, resulting in 26 fatalities, with hypothermia or illness (47%) and accidents (24%) identified as the main causes [2]. Although these incidents are influenced by environmental conditions, the high proportion of preventable factors suggests potential gaps in climbers' safety preparedness, particularly among beginners. Many novice climbers are attracted by mountain scenery presented on social media without sufficient awareness of climbing safety risks and emergency handling procedures. This condition indicates that existing pre-climbing safety induction may not effectively promote procedural understanding and situational awareness. Current safety induction methods remain largely theoretical, relying on text-based materials, information boards, or verbal briefings that are less engaging and limited in conveying practical, contextual knowledge [3]. Therefore, more interactive and visual learning media are needed to enhance safety comprehension and preparedness among beginner climbers.

Augmented reality (AR) technology has proven effective in delivering safety-related information in an immersive and interactive manner by integrating virtual objects into real environments in real time[4][5]. AR is supported by features such as object tracking, zoom in–out, animation, and audio [6], and aims to enrich real-world objects with contextual information [7]. Several Scopus-indexed studies have demonstrated that AR-based safety training significantly improves learning effectiveness, engagement, and knowledge retention compared to conventional training methods, particularly in laboratory and industrial safety contexts[8][9]. However, most existing AR-based safety or outdoor education applications rely on marker-based tracking or are designed for controlled indoor environments, limiting their applicability in dynamic outdoor or pre-climbing contexts. In Indonesia, AR research has predominantly focused on educational applications, such as AR for fruit education using markerless techniques [10], markerless AR for interactive learning media [11], and AR applications for Internet of Things component learning [12], which are generally implemented in indoor or classroom settings. Similarly, other AR research in national journals continues to emphasize marker-based visualization techniques for interactive learning[13], Although these studies demonstrate AR's potential for enhancing engagement and visualization, they do not specifically address safety induction or situational preparedness in real outdoor environments. This gap highlights the need for a markerless AR approach tailored to pre-climbing safety preparation [14].

This study is grounded in Experiential Learning Theory (Kolb), which posits that effective learning occurs through a cycle of concrete experience, reflective observation, abstract conceptualization, and active experimentation [15] .In the context of climbing safety, immersive AR enables novice climbers to virtually experience equipment usage and emergency handling procedures before encountering real risks, thereby facilitating experiential and contextual learning [16]. Furthermore, the study aligns with Multimedia Learning Theory (Mayer), which suggests that learners achieve deeper understanding when verbal explanations are integrated with meaningful visual representations rather than delivered through text alone[17] . By combining real-time three-dimensional visualization, animation, audio, and spatial interaction through markerless tracking [6][7], the proposed application supports improved comprehension, retention, and situational awareness[18]. The novelty of this research lies not merely in adopting markerless AR technology, but in its specific methodological and contextual application to mountain climbing safety induction conducted prior to outdoor activities [14].

Based on the identified gap and theoretical foundation, this research aims to develop and evaluate an Android-based markerless augmented reality application to enhance pre-climbing safety induction for beginner climbers. The developed application presents interactive three-dimensional AR models to deliver safety induction information [19] and is developed using Blender and Unity, equipped with zoom and audio features to support multimodal learning. Practically, markerless AR improves accessibility and usability, as it can be used anytime and anywhere without additional physical markers, making it suitable for outdoor safety education. By integrating immersive visualization with mobile accessibility, this study contributes both technologically and pedagogically to strengthening procedural understanding, situational awareness, and safety preparedness among novice climbers before undertaking real climbing activities.

2. Research method

This study employed a development-oriented research approach in the form of applied system development, focusing on the design and implementation of an Android-based markerless augmented reality (AR) application for mountain climbing safety induction. The Multimedia Development Life Cycle (MDLC) method was selected because it is specifically designed for multimedia-based applications that integrate visual, audio, and interactive components, making it more suitable than general instructional models such as ADDIE, which primarily emphasize pedagogical planning rather than technical multimedia implementation. MDLC consists of six structured stages: concept, design, material collection, assembly, testing, and distribution[6].

The concept stage defines application objectives and AR functionality, followed by the design stage, which structures user interfaces and navigation. The material collection stage gathers multimedia assets, while the assembly stage integrates these assets into a functional markerless AR system using surface detection. Markerless AR was chosen due to its practical advantages in outdoor and mobile contexts, as it eliminates dependency on physical markers and allows flexible object placement in real environments, which has been shown to enhance usability and immersion in educational applications [20]. After development, the application was tested using the black-box testing method, focusing on functional validation without examining internal system structure [21]. User evaluation was conducted through a Likert-scale questionnaire involving 20 beginner climbers to assess usability and perceived learning effectiveness. Although the number of participants is relatively limited, this sample size is considered adequate for preliminary usability and feasibility testing in development-based research, where the primary objective is functional validation rather than large-scale generalization. Similar AR development studies have employed small user groups to evaluate system performance and user acceptance in safety training and interactive learning contexts. Nevertheless, the limited sample size represents a methodological constraint, and future studies are recommended to involve a larger and more diverse participant population to enhance generalizability. Ethical considerations were observed throughout the study: all participants provided informed consent prior to data collection, participation was voluntary, and respondent data were anonymized to ensure confidentiality [22]. Finally, the application was distributed by uploading it to the Google Play Store [23].

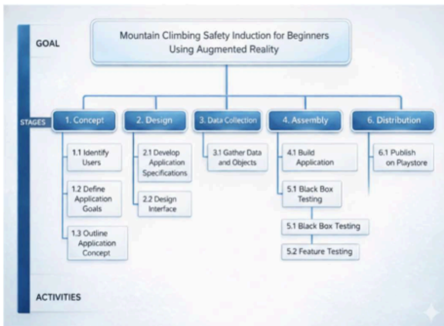

***Figure 1.** Work Breakdown Structure*

Work Breakdown Structure (WBS) is a hierarchical diagram arranged from top to bottom in order to divide the work process into more detailed parts. This approach helps in management and control during the implementation of research [24]. After the WBS is compiled, the next step is to discuss each stage of the research that has been carried out in accordance with the objectives and research methods.

3. Results

Concept

The initial stage for WBS is conceptualization. This stage involves determining the target users of the application, its objectives, and the concepts that will be utilized when creating the application [21].

1) At the user identification stage, activities carried out included searching for data sources through literature studies, followed by the application being focused on beginner climbers
2) The application for this research aims to help beginner climbers understand how to use climbing equipment properly and how to deal with emergency situations.
3) The concept applied in this research is the development of media-based applications on Android smartphones. This application will be created using Blender and Unity 3D software.

***Table 1**. Description of application concepts*

No	Fitur	Deskripsi
1	Title	Mountain Climbing Safety Induction for Beginners Using Augmented Reality
2	User	Beginner Climber
3	Features	Home screen, Start, 3D Scan, About, Guide, Exit
4	Figure	Image, Background, button
5	Interaction	Application home screen, main menu, start, 3D AR scan, about, Help, menu, exit

Design

The next stage is design, which focuses on determining application specifications and designing the interface. The application specifications are shown in the flowchart in Figure 2. The flowchart diagram illustrates each step in the process using symbols connected by lines and arrows. Not only that, the use of flowcharts in the program makes the workflow clearer, concise, and minimizes the possibility of misunderstandings [24]. The flowchart explains the design of the mountain safety induction application for beginner climbers. When opening the application, the user will be shown the initial display, where they can choose to enter the main menu or exit to close the application. In the main menu, there are four buttons, namely start, about, guide, and exit. If you select start, you can choose the equipment usage or emergency situation handling menu. After that, you can select one of the objects, and after selecting the object, you will be directed to the safety induction tutorial and 3D scan. The about menu contains a brief explanation of the application. The guide menu contains a tutorial on using the application, while the exit menu is for ending the use of the application.

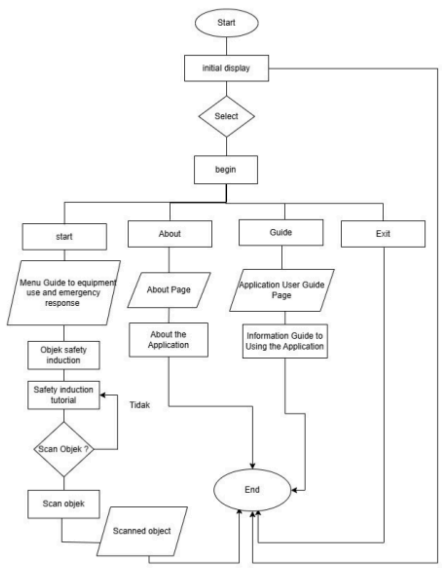

***Figure 2.** Flowchart*

The next step is to design the application interface. The application interface is presented in the form of an interface design. Interface design is a step in designing how a software system looks and how visual interactions occur [25]. Figure 3 shows the interface design of a mountain climbing safety induction application for beginner climbers using Augmented Reality.

The assembly stage is the process in which all designs and materials are realized. At this stage, all components or items are developed and integrated to form a complete application [26]. The initial stages of application development include gathering materials, creating three-dimensional models, creating EasyAR accounts, and connecting them to Unity. Next, the menu display is designed, the three-dimensional models are integrated into the application, and the final stage is the application build process using Unity tools.

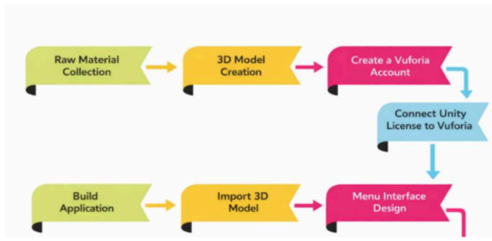

Figure 3. *Application assembly flow*

The assembly process results in an application that emphasizes three-dimensional object visualization as its main concept. Figure 3 illustrates the basic interaction concept between users and three-dimensional objects within the application. Meanwhile, Figure 4 presents the main application features, particularly the display and interaction of 3D character models during application execution

Smartphone android — *Flat surface* — *3D object*

Figure 4. *Interactive implementation of the application*

Table 2. *Black-box testing*

No	Features	Tes Results			Description
		Good	Poor	No	
1	Initial display showing entry and exit	✔			successful
2	Main screen containing the start menu, about, guide, and exit	✔			successful
3	Safety object selection page Induction	✔			successful

4	The equipment usage page displays the climbing equipment button.	✓	successful
5	The emergency response page displays an accident button for climbers.	✓	successful
6	Each equipment usage button can be clicked to display a safety induction tutorial and Ar scan.	✓	successful
7	Each emergency response button can be clicked to display a safety induction tutorial scan and an ar scan.	✓	successful
8	Tombol scan Ar dapat dibuka dan kamera dapat digunakan	✓	successful
9	Scan the tent	✓	successful
10	Scan portable stove	✓	successful
11	Scan sleeping bag	✓	successful
12	Scan compass	✓	successful
13	Scan headlamp	✓	successful
14	Scan sprained foot	✓	successful
15	Scan minor scratches	✓	successful
16	Scan hipotermia	✓	successful
17	Start button	✓	successful
18	Equipment usage button	✓	successful
19	Emergency response button	✓	successful
20	About Button	✓	successful
21	Help button	✓	successful
22	Exit button on the main page	✓	successful
23	Back button	✓	successful
24	Login button	✓	successful
24	Exit button on the home page	✓	successful

Table 2 shows the results of black box testing on the application. Testing began from the initial screen, which has a login and logout button. Next, the user enters the main page and selects the start menu to launch the application. In this menu, the user can choose equipment usage or emergency situation handling, then select the desired object to enter the safety induction tutorial page. On this page, there is a 3D scan button to display three-dimensional objects. In addition, on the main page there are also menus about, guide, and exit to close the application.

Table 3. *Smartphone test results*

No	Device name mobile phone	Andrid version	RAM	Plugin Easy Ar	Results
1	Realme c75x	Android 15	8+16	Yes	The application runs smoothly
2	Vivo 2019	Android 12	4	Yes	The application runs smoothly
3	Samsung galaxy A07	Android 15	4	Yes	Does not support the Easy Ar plugin
4	Samsung Galaxy S7 Edge	Android 8	4	Yes	The application runs smoothly
5	Samsung galaxy note 9	Android 11	6	Yes	The application runs smoothly

Table 3 shows the results based on device compatibility testing conducted on five different Android smartphones with varying specifications and operating system versions, the results indicate that the application can run smoothly on most tested devices. The application performed well on devices with Android versions ranging from Android 8 to Android 15 and RAM capacities between 4 GB and 16 GB. However, one device, the Samsung Galaxy A07, was unable to support the Easy AR plugin, indicating that certain hardware or software limitations may affect compatibility with specific AR frameworks. Overall, the findings demonstrate that the developed application is generally compatible across a wide range of Android devices, although support for markerless AR features may depend on device capabilities.

Tabel 4*. Skor Skala Likert*

Category	Presentase	Description
1	0% - 20%	Very poor
2	21% - 40%	Poor
3	41% - 60%	Fair
4	61% - 80%	Good
5	81% - 100%	Very Good

Table 4 presents the feasibility assessment criteria using a Likert scale of 1 to 5, ranging from the lowest to the highest classification. This feasibility assessment was conducted by distributing questionnaires to respondents to measure the visual aspects, functionality, and effectiveness of the application. All participants were asked to provide a comprehensive assessment based on their user experience.

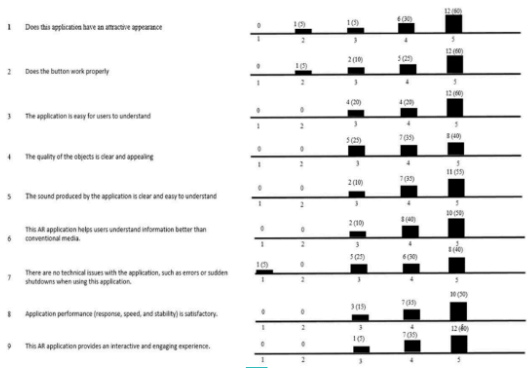

Figure 5. *Graphical results of the user experience questionnaire*

Based on Figure 5 from the questionnaire results obtained from beginner climbers, there were 20 respondents with a score of 5, totaling 95; a score of 4, totaling 57; a score of 3, totaling 25; a score of 2, totaling 2; and a score of 1, totaling 1 respondent. The formula for assessing respondents' responses to the augmented reality safety induction application for beginner climbers on a Likert scale. The highest score is marked with an X, and the highest score is in the "optimal performance" category with a score of 5. The score obtained is the number of questions multiplied by the questionnaire submitted, namely X = 5 x 9 = 45. The expected score is represented by Y, then calculated by multiplying that value by the number of respondents determined, Y = 45 x 20 (number of respondents) = 900.

f = Total frequency value for each question

P = Feasibility presentation

T = Total respondents

Y = Expected score

Pn = Likert score

Therefore, the user satisfaction calculation results are:

$$f = T \times Pn \quad (1)$$

$$f = (95 \times 5) + (57 \times 4) + (25 \times 3) + (2 \times 2) + (1 \times 1)$$

$$f = 475 + 228 + 75 + 4 + 1 = 783$$

$$p = f/y \times 100\% = P\% \quad (2)$$

$$p = 783/900 \times 100\% = 87\%$$

Based on the analysis results, the Augmented Reality Safety Induction Mountain Climbing application developed for beginner climbers obtained a feasibility score of 87%. Compared to conventional safety induction methods such as direct briefings, reading materials, and educational videos, AR-based media shows advantages in increasing user engagement and providing a more immersive learning experience. These results are in line with scientific studies on safety training, which state that the use of AR is generally more effective than traditional methods, especially in increasing engagement and learning retention, although the difference in knowledge acquisition is not always statistically significant. A meta-analysis of various studies also shows that AR is superior in delivering complex material. Therefore, the developed AR application can be considered highly effective and suitable for use as an educational medium for mountain climbing safety induction for beginner climbers [27].

At the distribution stage, the augmented reality mountain climbing safety induction application for beginner climbers will be published through the Google Play Store after the entire testing process has been completed. The testing includes user testing by a mountain climber. Next, this application will be implemented as an interactive learning medium to support educational activities.

Figure 6. *Testing by user*

4. Discussion

The results of this study indicate that the developed augmented reality–based mountain climbing safety induction application is feasible and well accepted by beginner climbers. The feasibility score of 87% obtained from the Likert scale questionnaire reflects positive user perceptions in terms of usability, visual clarity, interactivity, and perceived usefulness. These findings are in line with recent literature which reports that AR technology can significantly enhance safety training and immersive learning experiences by increasing engagement and active participation compared to traditional methods [28][29]. One of the key contributions of this study lies in the implementation of markerless AR technology for outdoor safety education. Unlike marker-based AR, which relies on printed markers, markerless AR allows users to interact with three-dimensional safety equipment models in flexible settings without additional physical tools. This characteristic supports experiential and situated learning principles, particularly in dynamic real-world environments such as mountain climbing, and aligns with findings that AR and extended reality technologies enrich safety training by creating realistic, interactive learning environments [30].

However, this study has several limitations that should be acknowledged. First, the number of respondents involved in the user evaluation was relatively small, consisting of only 20 beginner climbers, which limits the generalizability of the results. Second, this research did not include a pre–post learning evaluation to quantitatively measure improvements in safety knowledge or behavioral readiness; the evaluation focused mainly on user perception and system feasibility. As a result, while users reported positive experiences, the extent to which the application improves learning retention and safety behavior cannot be conclusively determined. Future research should incorporate experimental designs, such as pre-test and post-test assessments, to evaluate learning effectiveness more rigorously [29]. Third, the application's performance depends on specific AR plugins, such as the Easy AR plugin, which may not be fully supported on all Android devices, highlighting a technical limitation in AR deployment across diverse hardware.

From a pedagogical perspective, the findings of this study reinforce the potential of Augmented Reality (AR) technology as an effective tool for supporting outdoor education and safety training. The integration of interactive 3D visualization and real-time user interaction aligns with experiential learning and visual learning theories, which are particularly effective for procedural and risk-oriented training contexts. Recent studies indexed in Scopus indicate that AR can create immersive and interactive learning environments, enhancing learners' engagement, understanding of complex procedures, and situational awareness in safety training [31].

Specifically, comparative studies show that AR-based safety training is more effective in short-term knowledge acquisition and long-term retention than traditional slide-based methods, as observed in metro construction safety case studies [29]. These findings are consistent with experiential learning theory, emphasizing the importance of active engagement with real content in developing practical competencies and preparedness for risk situations.

5 Conclusion

Based on the results of this study, it can be concluded that the Mountain Climbing Safety Induction Application for Beginner Climbers contributes to the development of interactive safety education media by integrating markerless augmented reality technology into outdoor safety training. This research demonstrates how AR-based visualization can be effectively applied to present climbing equipment usage and emergency handling procedures in a more engaging and immersive manner compared to conventional safety induction methods. The use of markerless AR allows users to access three-dimensional learning content flexibly without the need for physical markers or actual equipment, thereby enhancing practicality and supporting visual and experiential learning for beginner climbers.

From a system evaluation perspective, the application was successfully validated through black-box testing, which confirmed that all functional features operated as intended. Furthermore, the user evaluation involving 20 respondents resulted in a feasibility score of 87%, categorized as good to very good. These findings indicate that the developed application is not only functionally reliable but also positively perceived by users as an educational medium for mountain climbing safety induction.

Nevertheless, this study has several limitations that should be considered. First, the evaluation involved a relatively small number of respondents, which may limit the generalizability of the findings. Second, the assessment focused on user perception and system feasibility without incorporating pre–post learning measurements to quantitatively evaluate knowledge improvement or behavioral readiness. In addition, the application's performance depends on specific augmented reality plugins, which may affect compatibility across different devices.

Future development of this application may include additional features such as evacuation route guidance, climbing route maps, and integrated emergency contact information. Moreover, future research is recommended to employ experimental evaluation methods and larger sample sizes to measure learning effectiveness more comprehensively. With further refinement, this application has strong potential to be utilized as a supporting learning medium in climbing training programs and outdoor education activities in accordance with applicable safety standards.

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