# Personalized User Experience and Engagement in Interactive Mobile Augmented Reality Software Through Fuzzy Weights

Christos Papakostas(✉), Christos Troussas, Akrivi Krouska, Phivos Mylonas, and Cleo Sgouropoulou

Department of Informatics and Computer Engineering, University of West Attica, Egaleo, Greece

{cpapakostas,ctrouss,akrouska,mylonasf,csgouro}@uniwa.gr

**Abstract.** The integration of digital content into the real world through mobile augmented reality (AR) systems presents captivating prospects, yet user engagement and experience within such environments are largely contingent upon individual computer skills, which can vary significantly among users, thereby influencing their proficiency in utilizing this technology. This paper aims to bridge this gap by examining the impact of users' computer skills on interactions within mobile AR settings. To this end, a novel fuzzy logic-based model is introduced to evaluate and refine users' computer skills within the realm of mobile AR systems. By modeling users' computer aptitude, the system is capable of delivering tailored assistive prompts and feedback. These prompts are strategically aligned with established fuzzy weights, thereby augmenting users' interactions within the mobile AR sphere. The proposed methodology is seamlessly integrated into a personalized mobile AR platform designed for spatial ability training. Evaluation findings reveal promising outcomes, underscoring the substantial potential of fuzzy logic modeling to elevate user experiences and propel advancements in mobile augmented reality technology.

**Keywords:** Fuzzy logic · Mobile augmented reality · Spatial ability training · Intelligent tutoring system · Computer skills · Feedback · Assistive messages · Personalization · Education

## 1 Introduction

Recent advancements in augmented reality (AR) technology, particularly in the realm of mobile AR, have uncovered significant opportunities across various applications, spanning entertainment such as gaming, as well as educational and professional training contexts [1]. Mobile AR provides users with an immersive experience that seamlessly blends digital and physical worlds, enabling virtual elements to be integrated into the real environment through mobile devices [2]. Despite the potential advantages offered by mobile AR, users often encounter challenges when interacting with these systems. These challenges may stem from a lack of familiarity with the technology, limited proficiency


M. Marchiori and F. García Peñalvo (Eds.): WEBIST 2023, LNBIP 543, pp. 245–266, 2025.
https://doi.org/10.1007/978-3-031-89621-7_13

in computer skills, or an insufficient understanding of the capabilities and functionalities of such systems [3].

In addition to these challenges, users may also face issues related to spatial orientation, cognitive load, and user interface complexities, which can hinder their overall experience and limit the effectiveness of mobile AR applications [4]. Moreover, the diverse range of user backgrounds, preferences, and skill levels further complicates the design and implementation of user-friendly mobile AR interfaces [5].

To address these challenges and enhance user engagement in mobile AR environments, there is a growing interest in leveraging advanced technologies such as fuzzy logic-based modeling [6]. By incorporating fuzzy logic techniques, mobile AR systems can dynamically adapt to users' individual characteristics and preferences, providing personalized assistance and guidance tailored to their specific needs and skill levels [7, 8]. This approach not only improves user interactions within mobile AR settings but also contributes to a more inclusive and accessible user experience for individuals with varying levels of technological proficiency.

As mobile AR continues to evolve and diversify across different domains, further research efforts are needed to explore innovative strategies for enhancing user engagement, mitigating usability challenges, and maximizing the potential benefits of this transformative technology. Through interdisciplinary collaborations and a user-centered design approach, researchers and practitioners can work together to unlock new opportunities and drive advancements in the field of mobile AR.

The proficiency level and technological acumen of users constitute pivotal factors influencing their capacity to engage effectively with mobile augmented reality (AR) systems. Individuals possessing advanced computer skills and knowledge tend to exhibit greater adeptness in navigating and harnessing the features and capabilities of mobile AR applications. Conversely, those with limited computer literacy may encounter challenges in comprehending and leveraging the diverse interaction modalities and functionalities inherent in mobile AR platforms. Hence, there arises a pressing need to model and assess users' computer skills and knowledge [9–11] as a means of optimizing interaction paradigms and augmenting the overall user experience within mobile AR environments.

Moreover, the effective modeling of users' computer skills and knowledge not only facilitates tailored guidance and support but also fosters inclusivity by accommodating individuals across varying proficiency levels. By incorporating insights from cognitive science and human-computer interaction, researchers can develop sophisticated models that dynamically adapt to users' cognitive abilities and learning preferences, thereby promoting a more intuitive and user-centric interaction framework in mobile AR systems. Additionally, the integration of machine learning algorithms and data-driven approaches holds promise for enhancing the accuracy and granularity of user skill assessments, enabling personalized recommendations and interventions to optimize user engagement and satisfaction in mobile AR contexts.

Numerous methodologies exist for modeling users' computer skills and knowledge within the realm of mobile augmented reality (AR) systems. One prominent approach is fuzzy logic, a technique acknowledged for its capacity to handle imprecise and uncertain data [12–14]. Fuzzy logic offers a versatile framework for representing and analyzing the ambiguity and unpredictability inherent in users' computer competencies. By employing fuzzy logic-based models, it becomes feasible to evaluate users' computer skills along a spectrum rather than relying on a binary classification. This nuanced approach facilitates a deeper understanding of users' proficiency levels and enables the customization of interaction experiences within mobile AR systems.

In addition to fuzzy logic, enhancing user interaction in mobile AR systems can be accomplished through the integration of various techniques, such as feedback mechanisms and informative messaging [15, 16]. Feedback mechanisms serve to guide users, furnish assistance, and offer real-time recommendations to augment their comprehension and utilization of mobile AR functionalities. Concurrently, informative messages can be deployed to apprise users of specific features, tips, or updates pertinent to the mobile AR application they are utilizing. These enhancements collectively aim to elevate the user experience, foster heightened engagement, and facilitate more efficient interactions within mobile AR environments.

Furthermore, the implementation of these techniques underscores a broader effort to develop user-centered design principles tailored to the unique attributes and requirements of mobile AR users. Through iterative refinement and user feedback, designers and developers can iteratively optimize mobile AR applications to better align with users' needs, preferences, and skill levels. By prioritizing user engagement and interaction fluidity, these advancements contribute to the ongoing evolution and maturation of mobile AR technology, fostering its broader adoption across diverse domains and user demographics.

This study focuses on the examination of users' computer proficiencies and their consequential impacts on interactions within mobile augmented reality (AR) systems. In pursuit of this objective, a novel fuzzy logic-based model is introduced to evaluate and refine users' computer skills within the context of mobile AR environments. The evaluation of users' computer aptitude concerning their interactions with mobile AR environments was conducted through a meticulously crafted questionnaire, developed by domain experts to target various facets of mobile AR interaction. Furthermore, this paper illustrates the integration of the proposed approach into a personalized mobile AR system designed specifically for spatial ability training. Within this framework, users receive tailored assistive messages and feedback based on the established fuzzy weights derived from the fuzzy logic-based model. Through this personalized approach, users are guided and supported in navigating the mobile AR environment, thus enhancing their overall experience and efficacy in spatial ability training. The evaluation findings reveal a notably positive outlook, underscoring the efficacy and promise of fuzzy logic modeling in bolstering user experiences within mobile AR contexts. This positive reception underscores the potential of leveraging fuzzy logic techniques not only to optimize user interactions but also to propel advancements in mobile AR technology.

The present paper is an extended and updated version of our preliminary conference paper that was presented in [6]. This paper significantly expands the evaluation of the proposed mobile AR system through fuzzy logic.

## 2 Related Work

Analyzing the body of literature pertaining to mobile augmented reality (AR) systems reveals a notable surge in growth over recent years. Research endeavors within this domain predominantly concentrate on enhancing the user experience, refining interface design for greater user-friendliness, and introducing novel forms of interaction [17–35]. Additionally, there is a growing emphasis on infusing intelligence into these systems to facilitate user modeling and knowledge representation [7, 8, 36–39]. The incorporation of intelligence into mobile AR systems encompasses a spectrum of techniques, with fuzzy logic emerging as a noteworthy approach among them.

Fuzzy logic offers a robust methodology for handling uncertainty and imprecision, making it well-suited for modeling user behavior, preferences, and knowledge within the context of mobile AR applications. By leveraging fuzzy logic-based models, researchers can effectively capture the nuances of user interactions and tailor AR experiences to align with individual user profiles.

In addition to fuzzy logic, advancements in artificial intelligence (AI) and machine learning (ML) have also contributed to the intelligence augmentation of mobile AR systems. Techniques such as neural networks, deep learning, and reinforcement learning are being explored to enable more sophisticated user modeling, context awareness, and adaptive system behavior. These intelligent capabilities pave the way for personalized AR experiences that are finely tuned to meet the unique needs and preferences of individual users.

Considering the discussed developments, it can be inferred that there exists a notable gap in the literature concerning the personalization of such systems. While considerable attention has been devoted to improving user interface and friendliness, there remains a dearth of research addressing the customization of mobile AR experiences to individual user characteristics and preferences. This gap underscores the need for further exploration into personalized approaches that can tailor mobile AR systems to the unique needs and preferences of users, thereby maximizing engagement and satisfaction.

## 3 Fuzzy Weighting Framework

Supporting users of mobile AR systems necessitates a nuanced understanding of their computer skills, a multifaceted undertaking fraught with uncertainties. In our investigation, we adopted a rigorous methodology leveraging a questionnaire devised by a consortium of 15 faculty members of informatics from public universities. The questionnaire comprised 10 questions, each carefully designed to gauge proficiency levels across a spectrum. Participants were tasked with selecting from a range of options for each query, with each option corresponding to a distinct proficiency grade. For instance, option A corresponded to a single grade, while option B warranted two grades, and so forth, culminating in a maximum grading potential of 40 for each participant.

The questionnaire's design was intricately tailored to probe participants' knowledge base and hands-on experience with mobile augmented reality systems, thereby offering valuable insights into their aptitude and familiarity with the technology. Table 1 presents a comprehensive overview of the questionnaire items, delineating the specific inquiries devised to elicit nuanced responses from participants.

**Table 1.** Questionnaire.

| Questions | Answers |
|---|---|
| How would you rate your knowledge of AR technology? | a) Limited or no knowledge<br>b) Basic understanding<br>c) Moderate understanding<br>d) Advanced knowledge |
| Have you previously used AR applications? | a) No<br>b) Yes, but only a few times<br>c) Yes, occasionally<br>d) Yes, frequently |
| How comfortable are you with using mobile devices? | a) Not comfortable at all<br>b) Somewhat comfortable<br>c) Moderately comfortable<br>d) Very comfortable |
| How familiar are you with the concept of virtual objects and their interaction in AR? | a) Not familiar at all<br>b) Somewhat familiar<br>c) Moderately familiar<br>d) Very familiar |
| How proficient are you in installing and setting up AR applications on a mobile device? | a) Not proficient at all<br>b) Basic proficiency<br>c) Moderate proficiency<br>d) Advanced proficiency |
| How comfortable are you with the process of calibrating an AR system to align virtual objects with the real world? | a) Not comfortable at all<br>b) Somewhat comfortable c) Moderately comfortable<br>d) Very comfortable |
| How experienced are you in creating or designing augmented reality experiences? | a) No experience<br>b) Limited experience<br>c) Moderate experience<br>d) Extensive experience |
| How knowledgeable are you about the different types of AR technologies, such as marker-based, marker-less, or projection-based AR? | a) Limited knowledge<br>b) Basic knowledge<br>c) Moderate knowledge<br>d) Advanced knowledge |
| How confident are you in troubleshooting common issues that may arise while using AR applications or devices? | a) Not confident at all<br>b) Somewhat confident<br>c) Moderately confident<br>d) Very confident |
| How comfortable are you with integrating AR technology with other digital tools or platforms, such as social media or e-learning systems? | a) Not comfortable at all<br>b) Somewhat comfortable<br>c) Moderately comfortable<br>d) Very comfortable |

For example, categorizing a user with a computer knowledge test score of 7.5 out of 10 as either “good” or “very good” presents a challenge due to the inherent ambiguity in such classifications, as both designations hold some degree of validity. To address this complexity, fuzzy logic emerges as a viable solution. In this paradigm, learners’ computer skills are delineated by four fuzzy weights: Novice (N), Basic (B), Advanced (A), and Proficient (P), each characterized by trapezoidal membership functions (refer to Table 2 and Fig. 1). These functions are defined by four boundary values ($a_1$, $a_2$, $a_3$, $a_4$), wherein the degree of membership gradually ascends from 0 to 1 between $a_1$ and $a_2$, remains constant at 1 between a2 and a3, and then descends from 1 to 0 between $a_3$ and $a_4$. Trapezoidal membership functions were specifically selected for their ability to accurately delineate the interval within which students’ scores unequivocally belong to a specific knowledge category.

Expanding on this framework, the incorporation of fuzzy logic not only addresses the challenge of categorizing users with nuanced skill levels but also enables a more detailed and granular representation of learners’ proficiencies. By employing trapezoidal membership functions (Table 2), the fuzzy logic model accommodates the inherent uncertainty and imprecision associated with human cognition (Fig. 1), thereby facilitating a more flexible and adaptable approach to assessing and refining users’ computer skills within the context of mobile augmented reality systems. This sophisticated framework lays the groundwork for personalized and targeted interventions aimed at enhancing user engagement and interaction efficacy in mobile AR environments.

As reiterated earlier, the current methodology employs membership functions to represent a user’s current level of computer knowledge in AR interactions. These membership functions serve as the basis for defining the values of the fuzzy weights, ranging from 0 to 1. A value of 1 assigned to the knowledge level indicates that the user has attained mastery in the domain and possesses comprehensive understanding. Consequently, the cumulative value of each segmented fuzzy set signifies the knowledge level of a domain learning unit and collectively sums up to 1, as denoted by the equation $\mu_N(x) + \mu_B(x) + \mu_A(x) + \mu_P(x) = 1$.

The establishment of the fuzzy weights and the determination of thresholds for their membership functions were entrusted to a panel of 15 faculty members from esteemed public universities specializing in informatics. These seasoned faculty members were tasked with furnishing descriptive definitions of learners’ computer knowledge levels throughout the learning continuum, along with delineating the ranges of achievement corresponding to each knowledge level. Leveraging their extensive collective experience spanning over 12 years in university settings, these faculty members possess the requisite expertise to accurately depict users’ computer knowledge skills.

Furthermore, the engagement of domain experts in this process ensures the robustness and validity of the fuzzy weighting framework, instilling confidence in the accuracy and reliability of the fuzzy logic model utilized for assessing and refining users’ computer skills within the AR domain. Their contributions not only enrich the methodology but also enhance the credibility and applicability of the research findings within both academic and practical contexts.

**Table 2.** Membership functions [6].

| Computer Knowledge Level |
|---|
| **Membership Function** |
| Novice (N) |
| $\mu_N(x) = \begin{cases} 1 & x \leq 10 \\ 1 - \frac{x-10}{5} & 10 < x < 15 \\ 0 & x \geq 15 \end{cases}$ |
| Basic (B) |
| $\mu_B(x) = \begin{cases} \frac{x-10}{5} & 10 < x < 15 \\ 1 & 15 \leq x \leq 20 \\ 1 - \frac{x-20}{5} & 20 < x < 25 \\ 0 & x \leq 10 or x \geq 25 \end{cases}$ |
| Advanced (A) |
| $\mu_A(x) = \begin{cases} \frac{x-20}{5} & 20 < x < 25 \\ 1 & 25 \leq x \leq 35 \\ 1 - \frac{x-35}{2} & 35 < x < 37 \\ 0 & x \leq 20 or x \geq 37 \end{cases}$ |
| Proficient (P) |
| $\mu_P(x) = \begin{cases} \frac{x-35}{2} & 35 < x < 37 \\ 1 & 37 \leq x \leq 40 \\ 0 & x > 40 \end{cases}$ |

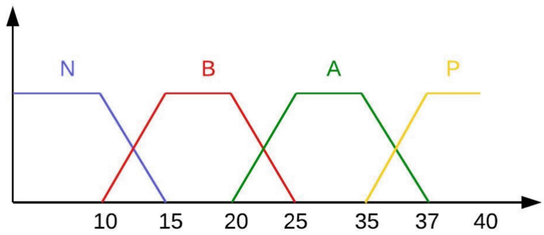


**Fig. 1.** Schemes of Fuzzy Weights [6].

## 4 Facilitating Assistive Messages Delivery

This section offers a comprehensive overview of the personalized assistive messages and feedback meticulously tailored to correspond with the fuzzy weights previously established. These bespoke messages are strategically disseminated to users at various junctures throughout their interaction with the mobile AR environment, with the overarching objective of enriching their overall experience and fostering deeper engagement with the technology.

Each fuzzy weight encompasses several categories of assistive messages. These are provided to the user randomly, offering diverse avenues for support. For instance, within the novice user category, specific message categories include the "Initiation Phase", "Discovery and Movement", and "Support and Advice". After determining the user's fuzzy weight, the system selects the most relevant message category for each interaction. To achieve this, the system employs an if-then algorithmic approach taking into consideration the user's interaction history as well as the prevailing task or context.

Moreover, within each designated category, the system employs a random selection process to choose a message tailored to the individual user, ensuring a personalized and customized experience. This dynamic approach enables users to receive targeted assistance and guidance that aligns with their proficiency level and immediate needs, thereby enhancing user satisfaction and efficacy in navigating the mobile AR environment.

### 4.1 Feedback to Novice Users

Novice users, characterized by their limited or nonexistent prior experience with AR systems, necessitate comprehensive, step-by-step instructions and guidance to navigate the system, utilize basic features, and grasp the interface. The personalized feedback messages tailored for novices encompass:

**Initiation Phase.** This section introduces the preliminary messages aimed at guiding and assisting novice users during their initial engagements with the AR system. The messages are as follows:

- "Welcome to the world of augmented reality! Let's start by guiding you through the basic features. Follow the step-by-step instructions to navigate the system and explore virtual objects."
- "To interact with virtual objects, simply tap on them. Try tapping on the floating cube to see it respond!"
- "Remember to maintain a comfortable distance from virtual objects for better interaction. Experiment with different gestures to explore their functionalities."

Additionally, these introductory messages serve as the cornerstone for novice users, offering clear and concise guidance to facilitate their acclimatization to the AR environment and empower them to explore its potential with confidence.

**Discovery and Movement.** In this segment, we introduce informative messages tailored to aid users in navigation and exploration tasks within the mobile AR system. The messages are outlined as follows:

- "To navigate through the AR environment, swipe left, right, up, or down to move around and discover more virtual content."
- "Do not be afraid to explore! Move your device around to find hidden objects and discover exciting AR experiences."

- "If you're feeling lost, refer to the on-screen guide or consult the user manual for assistance in navigating the AR environment."

Moreover, these informative messages serve as valuable navigational aids, empowering users to seamlessly navigate the AR landscape while fostering a sense of curiosity and discovery.

**Support and Advice.** This section introduces contextual messages meticulously crafted to furnish users of the mobile AR system with assistance and guidance. The messages are outlined as follows:

- "Do not worry if you are unsure about something. Remember, you can always refer to the user guide for detailed explanations and helpful tips."
- "If you need assistance at any point, tap on the help icon in the menu to access the FAQ section or get in-app support from our team."
- "Take your time to familiarize yourself with the interface and features. Learning at your own pace will help you build confidence in using augmented reality."

Furthermore, these personalized feedback messages tailored for novice users aim to offer lucid instructions, foster a spirit of exploration, and extend support when necessary. By receiving these messages, novices can gradually cultivate confidence and competence in navigating the augmented reality system.

## 4.2 Feedback to Basic Users

Basic users have acquired a degree of proficiency with AR systems and mobile devices. They are capable of executing routine tasks such as initiating the app, engaging with virtual objects, and configuring fundamental settings. Nonetheless, they may encounter occasional hurdles or seek guidance from user manuals to explore more intricate functionalities. The personalized feedback messages aimed at assisting basic users from the system are:

**Interactive Skill Enhancement.** This section introduces messages tailored to enrich the interaction experience for basic users within the mobile AR system. The messages are outlined as follows:

- "Congratulations on becoming familiar with augmented reality! Now, let's enhance your interaction skills. Experiment with different gestures to explore the functionalities of virtual objects."
- "To interact with virtual objects, tap on them, and observe how they respond. You can also try using long presses or double taps for additional actions."
- "Remember to maintain a comfortable distance from virtual objects for better interaction. Experiment with different gestures and distances to find what works best for you."

Moreover, these tailored messages aim to empower basic users by providing clear instructions, encouraging exploration, and promoting effective interaction practices.

Through these messages, basic users can further enhance their proficiency and enjoyment of the augmented reality experience.

**Advanced Functionality Exploration.** This section introduces messages tailored to facilitate the exploration of advanced features and functionalities for basic users within the mobile AR system. The messages are outlined as follows:

- "You're making great progress! It's time to dive into more advanced features. Explore the settings menu to customize preferences such as lighting, object placement, and interactions."
- "Adjust the sensitivity of your device's motion tracking to ensure a smoother and more immersive augmented reality experience."
- "Feel free to experiment with additional features like voice commands, object scaling, or integrating external data sources. Unlock the full potential of augmented reality!"

Furthermore, these customized messages aim to empower basic users by encouraging them to explore beyond the fundamentals, unlock advanced functionalities, and fully embrace the immersive possibilities of augmented reality. Through these messages, basic users can expand their horizons and discover the rich array of features available within the mobile AR environment.

**Support and Learning Tools.** In this segment, we present messages offering assistance and supplementary resources to aid basic users in their mobile AR interactions. The messages are outlined as follows:

- "If you encounter any challenges or have questions about specific features, refer to the user guide for detailed explanations and troubleshooting tips."
- "Don't hesitate to explore the help section in the app for quick access to FAQs and video tutorials. It can provide valuable insights and guidance."
- "As an intermediate user, your growing familiarity with the system enables you to explore new possibilities. Challenge yourself to discover hidden features or collaborate with other users to exchange tips and tricks."

These personalized feedback messages for basic users are designed to inspire further exploration, highlight advanced features, and offer assistance when necessary. By receiving these messages, basic users can continue to enhance their AR skills and deepen their comprehension of the system's capabilities.

### 4.3 Feedback to Advanced Users

Advanced users possess an extensive comprehension of the AR system and demonstrate proficiency in utilizing its functionalities. They exhibit adeptness in navigating intricate interfaces, tailoring settings to their preferences, seamlessly interacting with virtual objects, and resolving potential issues that may surface. The system delivers personalized feedback messages to advanced users, comprising:

**Enhancing Complex Interactions.** This section presents messages designed to assist advanced users in mastering intricate interactions within the mobile AR system. The messages are outlined as follows:

- "Impressive skills! You've mastered the basics and are ready for more advanced features. Navigate through the complex interface confidently and make the most of the additional tools at your disposal."
- "Experiment with advanced interactions such as multi-touch gestures, pinch-to-zoom, or two-finger rotations to manipulate and interact with virtual objects more precisely."
- "Consider exploring hand tracking or body tracking options for a more immersive and natural interaction with the augmented reality environment."

Furthermore, these tailored messages aim to empower advanced users by guiding them towards advanced features, offering suggestions for refining interaction techniques, and promoting exploration of innovative functionalities. Through these messages, advanced users can further elevate their mastery of the AR system and maximize their engagement with the augmented reality environment.

**Personalization and Performance Tuning.** In this section, we present messages crafted to aid advanced users in customizing and refining their experience within the mobile AR system. The messages are outlined as follows:

- "As an advanced user, customization is key. Dive into the settings menu to fine-tune preferences and tailor the augmented reality experience to your liking."
- "Optimize system performance by adjusting parameters like rendering quality, frame rate, or lighting effects. Maximize the quality and fluidity of your AR experiences."
- "Explore the advanced settings to enable features like occlusion, physics simulations, or real-time reflections. Push the boundaries of realism and create captivating AR scenes."

Furthermore, these tailored messages are designed to empower advanced users by guiding them through the customization process, optimizing system performance, and unlocking advanced features to elevate the quality of their AR experiences. Through these messages, advanced users can further refine their AR encounters and unleash their creativity to create immersive and captivating scenes.

**Expert Guidance and Problem Solving.** In this section, we present messages tailored to troubleshooting and offering support to advanced users within the mobile AR system. The messages are outlined as follows:

- "With your expertise, troubleshooting common issues becomes second nature. Share your knowledge with others in the community and offer assistance when needed."
- "Stay updated with the latest software updates and firmware releases to ensure compatibility, stability, and access to new features and improvements."
- "If you encounter more complex problems or need in-depth technical support, don't hesitate to reach out to our dedicated support team. They are available to assist you in resolving any challenges you may face."

These personalized feedback messages for advanced users recognize their proficiency and aim to empower them to explore advanced interactions, customize settings, and address issues effectively. By receiving these messages, advanced users can further hone their AR skills, enhance their experiences, and contribute to the AR community by sharing their knowledge and offering support.

### 4.4 Feedback to Proficient Users

Proficient users demonstrate high skills and extensive experience in navigating mobile AR systems. They boast a deep understanding of intricate features, excel in optimizing system performance, and may even possess the capability to craft or tailor their own augmented reality encounters. The system delivers personalized feedback messages to expert users, comprising:

**Expanding Creativity.** In this section, we introduce messages tailored to harnessing the creative potential of proficient users within the mobile AR system. The messages are outlined as follows:

- "Welcome, AR expert! Your knowledge and skills are highly valuable. Use your expertise to push the boundaries of augmented reality and unleash your creative potential."
- "Consider developing your own custom AR experiences using scripting or coding. Let your imagination soar and create unique interactive narratives or games."
- "Explore advanced techniques like object recognition, markerless tracking, or machine learning integration to create immersive and intelligent AR applications."

Furthermore, these messages are designed to inspire proficient users to venture into innovative avenues, experiment with advanced techniques, and pioneer groundbreaking AR experiences. Through these messages, proficient users can expand their horizons, push the boundaries of creativity, and leave their mark on the mobile AR landscape.

**Enhancing System Efficiency and Personalization.** This section presents messages concerning performance enhancement and personalization within the mobile AR system, as follows:

- "As an expert user, you have the power to optimize system performance. Fine-tune advanced settings like shaders, level of detail, or occlusion culling to achieve the best possible results."
- "Experiment with advanced lighting and shadow techniques to add depth and realism to your AR scenes. Leverage the full potential of the rendering engine to create visually stunning experiences."
- "Consider implementing performance optimization strategies such as asset bundling, texture compression, or dynamic resource loading to ensure smooth performance on various devices."

Moreover, these messages aim to empower expert users to maximize system efficiency, elevate visual quality, and ensure smooth performance across a range of devices.

Through these recommendations, expert users can further enhance their AR endeavors and deliver immersive experiences that captivate and engage audiences.

**Engagement and Knowledge Exchange.** In this section, we introduce messages centered on fostering collaboration and sharing within the mobile AR system, as follows:

- "Share your expertise with the AR community! Engage in forums, online communities, or developer conferences to exchange knowledge, collaborate on projects, and inspire others with your creations."
- "Consider publishing your AR experiences or apps on dedicated platforms to reach a wider audience and make a lasting impact in the world of augmented reality."
- "Remember to document your learnings, techniques, and best practices. By sharing your insights and tutorials, you can contribute to the growth and development of the AR ecosystem."

Furthermore, these messages aim to encourage users to engage with the AR community, share their creations, and contribute to the collective growth of the field. Through collaboration and knowledge-sharing, users can collectively propel the evolution and adoption of augmented reality technologies.

**Pioneering Technological Advancements.** This section introduces messages aimed at fostering cutting-edge research and innovation within the mobile AR system, as follows:

- "You are at the forefront of AR innovation! Stay informed about the latest advancements, research papers, and emerging technologies to continue expanding your expertise."
- "Consider exploring cutting-edge areas such as spatial mapping, real-time object recognition, or collaborative AR experiences. Push the boundaries of what's possible in augmented reality."
- "Share your findings and contribute to the advancement of the field through publishing research papers, attending conferences, or even mentoring aspiring AR developers."

These personalized feedback messages for expert users acknowledge their remarkable proficiency and encourage them to continue pushing the boundaries of augmented reality. By receiving these messages, expert users are inspired to explore advanced techniques, optimize performance, engage with the community, and drive ongoing innovation in the realm of augmented reality.

## 5 Evaluation Results and Discussion

In this section, we provide an assessment of the system's performance and efficacy.

### 5.1 Descriptive Analysis

The evaluation process extended over an entire academic semester and focused on spatial ability training tutoring within the framework of the undergraduate course "Educational

Technologies and IT Didactics" at a public university in the capital city. 80 undergraduate students participated in the evaluation. It is noteworthy that gender and age metrics were collected from a randomly selected sample and did not influence the research outcomes. The questionnaire (Table 3) was designed to gauge participants' familiarity, experience, and comfort levels with augmented reality (AR) technology.

Comprising six questions, the questionnaire explored various facets of AR, encompassing knowledge, usage, proficiency, familiarity with virtual objects, comfort with mobile devices, experience in crafting AR experiences, acquaintance with diverse AR technologies, troubleshooting skills, and integration of AR with digital tools. The responses aimed to offer valuable insights into participants' comprehension and competence in AR, aiding in pinpointing areas for enhancement and tailoring future AR-related initiatives to their preferences.

**Table 3.** Evaluation questionnaire [6].

| Constructs | Question |
|---|---|
| Personalization | Rate the effectiveness of the feedback messages you received regarding your AR usage and proficiency |
| | How well did the personalized feedback messages address your specific areas of improvement and help you enhance your understanding and skills in AR? |
| Design | Rate the user interface of the AR application you used |
| | How intuitive and user-friendly was the user interface of the AR application in terms of navigation, interactions, and accessing features? |
| User experience | How would you rate your overall user experience with the AR application? |
| | How likely are you to recommend it to others who are interested in exploring AR technology? |

To perform a descriptive analysis of the questionnaire responses, the authors aggregated the data by computing the frequency for each question (Fig. 2).

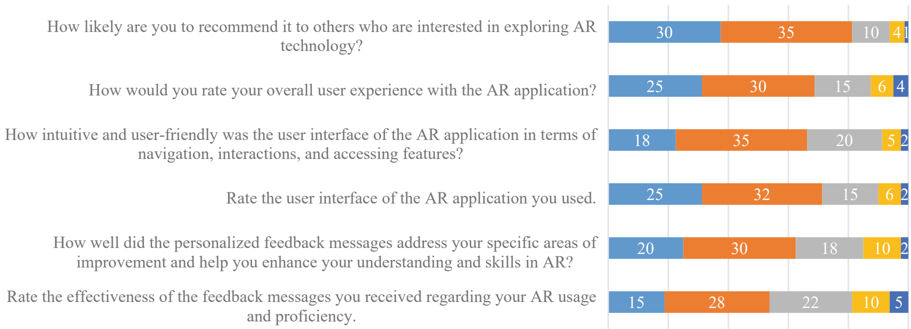


**Fig. 2.** Frequency of the answers in stacked-bar mode [6].

Based on participants' responses, the descriptive analysis offers intriguing insights into their familiarity, experience, and comfort level with AR technology.

The analysis of feedback message efficacy concerning AR usage and proficiency indicates that a significant portion of participants found the feedback helpful. Combining responses from the "extremely helpful" and "very helpful" categories, 53.75% of participants rated the feedback as highly advantageous. This suggests that the feedback messages provided valuable insights and guidance for enhancing participants' understanding and skills in AR. However, there is room for improvement, as 18.75% of participants expressed lower levels of effectiveness. This underscores the importance of tailoring feedback to address individual improvement areas and accommodating diverse proficiency levels.

Examining the effectiveness of personalized feedback messages in targeting specific improvement areas, results reveal that a notable percentage of participants (62.5%) felt the feedback adequately addressed their needs, rating it as either "very well" or "well." This signifies that personalized feedback messages effectively targeted specific improvement areas and enhanced participants' understanding and skills in AR. Nonetheless, addressing concerns from participants who found the feedback less effective (15%) is crucial to ensure a comprehensive and tailored approach.

Regarding the AR application's user interface, the analysis indicates that a majority of participants (71.25%) rated it as either "excellent" or "good." This suggests positive evaluation of the application's design and usability, indicating a satisfactory experience for most participants. However, not all ratings for the user interface were uniformly positive, with 10% expressing lower satisfaction levels. This underscores the importance of continuous refinement to cater to diverse user preferences and needs.

Overall, participants' ratings for their overall user experience with the AR application are predominantly positive. The majority (68.75%) rated their experience as either "excellent" or "good," suggesting the application provided a positive user experience, meeting expectations in performance, usability, and enjoyment. However, a small percentage of participants (12.5%) rated their experience as average or poor, indicating areas for improvement to enhance user satisfaction.

Concerning the likelihood of recommending the AR application to others interested in AR technology exploration, analysis reveals a positive inclination among participants. A significant majority (81.25%) expressed likelihood of recommending the application, either "very likely" or "likely." This high recommendation potential suggests participants perceived the AR application as valuable and beneficial, indicating an overall positive impression. Nonetheless, addressing concerns from participants expressing reluctance or neutrality (6.25%) is essential to maximize the application's reach and impact.

In conclusion, the descriptive analysis provides valuable insights into participants' perceptions and experiences with AR technology. It underscores the effectiveness of feedback messages, usability of the application's user interface, overall user experience, and likelihood of recommendation. These insights can inform further enhancements and refinements to the feedback process, user interface design, and overall AR experience, ultimately boosting engagement, satisfaction, and proficiency in AR technology.

### 5.2 Statistical Analysis

The instructors divided the student population into two cohorts, each comprising 40 students. The first group, termed the experimental group, was instructed to utilize an AR application featuring feedback messaging, while the second group, referred to as the control group, did not have access to the feedback generation module.

The incorporation of adaptive feedback messaging is pivotal in assessing the efficacy of an intelligent tutoring system integrating personalized feedback via fuzzy logic. To gauge users' perceptions of the system's ability to tailor feedback, a questionnaire was administered.

To determine if a statistically significant difference in personalized messages exists between students using the AR application with personalized feedback and those without, a *t*-test analysis was conducted. This analysis encompassed several steps:

- Formulation of the null hypothesis (H0) and alternative hypothesis (H1) based on the research inquiry and objectives.
- Selection of the significance level (alpha) to establish the threshold for accepting or rejecting the null hypothesis, with a value of 0.05 utilized for alpha.
- Collection of data from both the experimental and control groups.
- Computation of mean scores for each group separately, reflecting perceptions of personalized messages.
- Calculation of the variance for each group, indicating data spread or variability.
- Conducting the *t*-test to compare group means and evaluate statistical significance.
- Determination of the p-value associated with the calculated t-statistic, contrasting it with the significance level (alpha) to ascertain null hypothesis acceptance or rejection.
- Interpretation of findings: Rejection of the null hypothesis if the p-value is below the significance level, signifying a statistically significant difference in personalized messages between groups. Conversely, failure to reject the null hypothesis suggests no significant difference between the groups.

At the semester's end, both cohorts completed a questionnaire employing a 5-point Likert scale to express their agreement or disagreement, ranging from 1 (strongly disagree) to 5 (strongly agree).

To conduct the *t*-test analysis on the effectiveness of feedback messages regarding AR usage and proficiency between the experimental and control groups, ratings from both cohorts were compared. The *t*-test aimed to determine if there was a notable difference in group means.

Initially, the null hypothesis (H0) and alternative hypothesis (H1) were established as follows:

H0: There is no significant disparity in feedback message effectiveness between the experimental and control groups.

H1: A significant difference exists in feedback message effectiveness between the experimental and control groups.

Subsequently, a *t*-test analysis was performed using the ratings provided by both groups, resulting in the computation of t-values and p-values (Table 4).

Based on the t-value and degrees of freedom, we can ascertain the statistical significance of the findings. The p-value falls below the predetermined significance threshold

**Table 4.** t-test results [6].

| | Group A | Group B |
|---|---|---|
| Mean | 4.129 | 3.083 |
| Variance | 0.558 | 0.742 |
| Observations | 40 | 40 |
| Hypothesized Mean Difference | 0 | |
| df | 186 | |
| t Stat | 11.400 | |
| P (T ≤ t) one-tail | <.001 | |
| t Critical one-tail | 1.582 | |
| P (T ≤ t) two-tail | <.001 | |
| t Critical two-tail | 1.861 | |

of 0.05, leading us to reject the null hypothesis and infer a notable discrepancy in the efficacy of feedback messages between the experimental and control cohorts.

The *t*-test analysis unveils a t-statistic of 11.400, with 186 degrees of freedom, yielding a p-value below 0.001 for a one-tailed test. This indicates a statistically significant variance in the effectiveness of feedback messages between the two groups.

Under the null hypothesis (H0), no substantial difference is presumed between the two cohorts, whereas the alternative hypothesis (H1) posits a significant disparity. As the p-value is lower than the selected significance level, we dismiss the null hypothesis and confirm a significant contrast in the effectiveness of feedback messages between the experimental and control sets.

Furthermore, the *t*-test outcomes provide evidence that the mean effectiveness rating for the experimental group (M = 4.129) significantly surpasses that of the control group (M = 3.083). This implies that the feedback messages received by participants in the experimental cohort were more impactful in enhancing their comprehension and proficiencies in AR compared to their counterparts in the control group.

**Impact of AR on Spatial Abilities.** Given the potential of augmented reality to enhance spatial ability, an additional *t*-test was conducted to evaluate whether the use of AR technology significantly improves the spatial skills of students [40, 41]. This analysis aims to ascertain the effectiveness of AR in fostering spatial reasoning, a key skill in many educational and professional domains [42, 43].

The formulation of hypotheses is as follows:

H0: There is no significant difference in the improvement of spatial abilities between students who used the AR application and those who did not.

H1: Students who used the AR application show a significant improvement in spatial abilities compared to those who did not.

Before the experiment, all participants were tested to establish a baseline for their spatial abilities using a standard spatial reasoning test. At the end of the semester, the same test was administered again. The test scores from the beginning and the end of the semester were then used to assess improvements in spatial abilities.

The same cohorts of 40 students each from the experimental and control groups were involved. Pre-test and post-test scores on spatial reasoning were collected, while the mean improvement scores for each group were calculated by subtracting the pre-test scores from the post-test scores. The variances of these improvement scores were also computed. The *t*-test execution considered the alpha level at 0.05 and the results are presented in Table 5.

**Table 5.** t-test results of pre-test and post-test.

| | Group A | Group B |
|---|---|---|
| Pre-test Mean | 2.950 | 2.700 |
| Post-test Mean | 4.750 | 3.650 |
| Difference | 1.800 | 0.950 |
| Standard Deviation | 0.613 | 1.138 |
| Pearson Correlation | 0.112 | −0.462 |
| t Stat | −13.340 | −3.579 |
| p-Value | <0.001 | <0.001 |

The results presented in Table 5 provide a comprehensive overview of the impact of AR technology on enhancing spatial abilities among students. The primary focus of this analysis lies in interpreting the *t*-test results, particularly examining the significance of the differences between the pre-test and post-test scores of the two groups. Group A, which utilized AR technology, showed a substantial improvement in their post-test scores with a mean increase of 1.800, compared to Group B, which did not use the technology and showed a smaller increase of 0.950. This difference is statistically significant, as evidenced by the very low p-values (<0.001) for both groups, suggesting that the improvements in spatial abilities are not due to chance.

The magnitude of the mean differences further underscores the effectiveness of AR in fostering spatial reasoning skills. The greater improvement observed in Group A can be linked to the interactive and immersive nature of AR, which may enhance the learning experience by providing visual and spatial cues that aid in understanding complex spatial relationships. The standard deviation in the improvements (0.613 for Group A) indicates a relatively consistent effect across participants using AR. This consistency suggests that AR could be a reliable tool in educational settings for enhancing spatial abilities. Additionally, the negative t-values, particularly −13.340 for Group A, are indicative of a significant improvement from the pre-test to the post-test, further supporting the efficacy of AR in educational enhancements.

Lastly, the Pearson correlation coefficients present interesting insights into the relationship between the initial and improved performances of the students. For Group A, a positive but weak correlation (0.112) suggests little to no relationship between students' initial abilities and the extent of their improvement. In contrast, Group B exhibits a moderate negative correlation (−0.462), which could indicate that students with lower initial scores might have shown relatively more improvement than those with higher initial scores, albeit without the aid of AR technology. This contrasting dynamic between the groups could highlight the role of AR in providing a more uniform improvement in spatial skills, irrespective of initial ability levels, potentially leveling the educational playing field for all students. These findings advocate for the integration of AR applications in educational programs that aim to develop and enhance spatial reasoning skills, contributing significantly to students' learning outcomes in fields requiring strong spatial capabilities.

## 6 Conclusions

This paper presents a pioneering method for augmenting user interactions within mobile AR systems. It employs fuzzy logic-based modeling of users' computer skills to dynamically tailor personalized assistive messages and feedback. By employing fuzzy logic models, the system dynamically tailors personalized assistive messages and feedback to each user's unique level of computer proficiency, thus facilitating more effective navigation and utilization of mobile AR environments.

The evaluation outcomes highlight the efficacy of this approach, demonstrating its potential to refine user interactions and catalyze future advancements in mobile AR technology. However, it is essential to acknowledge certain limitations of the current methodology. For instance, the effectiveness of the fuzzy logic model may vary depending on the complexity of AR applications and the diversity of user skill levels. Additionally, the subjective nature of user feedback could introduce biases that may influence the accuracy of the fuzzy logic model.

Future endeavors will concentrate on the development of a hybrid algorithmic framework that integrates fuzzy logic with machine learning techniques to enhance the precision and adaptability of personalized message delivery. Furthermore, extensive user studies will be conducted to validate the effectiveness and robustness of the proposed approach across diverse user demographics and AR application scenarios.

**Disclosure of Interests.** The authors have no competing interests to declare that are relevant to the content of this article.

## References

1. Papakostas, C., Troussas, C., Krouska, A., Sgouropoulou, C.: Exploration of augmented reality in spatial abilities training: a systematic literature review for the last decade. Inform. Educ. **20**(1), 107–130 (2021). https://doi.org/10.15388/infedu.2021.06
2. White, G., Cabrera, C., Palade, A., Clarke, S.: Augmented reality in IoT. Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics). LNCS, vol. 11434, pp. 149–160 (2019). https://doi.org/10.1007/978-3-030-17642-6_13
3. Verma, A., Purohit, P., Thornton, T., Lamsal, K.: An examination of skill requirements for augmented reality and virtual reality job advertisements. Ind. High. Educ. **37**(1), 46–57 (2022). https://doi.org/10.1177/09504222221109104

4. Müller, T.: Challenges in representing information with augmented reality to support manual procedural tasks. AIMS Electron. Electr. Eng. **3**(1), 71–97 (2019)
5. Kourouthanassis, P.E., Boletsis, C., Lekakos, G.: Demystifying the design of mobile augmented reality applications. Multimed Tools Appl **74**(3), 1045–1066 (2015). https://doi.org/10.1007/s11042-013-1710-7
6. Troussas, C., Papakostas, C., Sgouropoulou, C.: Enhancing users' interactions in mobile augmented reality systems through fuzzy logic-based modelling of computer skills. In: Proceedings of the 19th International Conference on Web Information Systems and Technologies - WEBIST, SciTePress, pp. 381–390 (2023). https://doi.org/10.5220/0012204300003584
7. Pena-Rios, A., Hagras, H., Gardner, M., Owusu, G.: A fuzzy logic based system for mixed reality assistance of remote workforce. In: 2016 IEEE International Conference on Fuzzy Systems (FUZZ-IEEE). IEEE (2016). https://doi.org/10.1109/fuzz-ieee.2016.7737716
8. Papakostas, C., Troussas, C., Krouska, A., Sgouropoulou, C.: Personalization of the learning path within an augmented reality spatial ability training application based on fuzzy weights. Sensors **22**(18) (2022). https://doi.org/10.3390/s22187059
9. Irshad, S., Rambli, D.R.A., Sulaiman, S.: Design and implementation of user experience model for augmented reality systems. In: Proceedings of the 18th International Conference on Advances in Mobile Computing & Multimedia, in MoMM 2020, pp. 48–57. Association for Computing Machinery, New York (2021). https://doi.org/10.1145/3428690.3429169
10. Virvou, M., Troussas, C.: Web-based student modeling for learning multiple languages. In: International Conference on Information Society (i-Society 2011), pp. 423–428 (2011). https://doi.org/10.1109/i-Society18435.2011.5978484
11. Virvou, M., Troussas, C., Caro, J., Espinosa, K.J.: User modeling for language learning in Facebook. In: Sojka, P., Horák, A., Kopeček, I., Pala, K. (eds.) Text, Speech and Dialogue, pp. 345–352. Springer, Heidelberg (2012). https://doi.org/10.1007/978-3-642-32790-2_42
12. Campanella, P.: Neuro-fuzzy learning in context educative. In: 2021 19th International Conference on Emerging eLearning Technologies and Applications (ICETA), pp. 58–69 (2021). https://doi.org/10.1109/ICETA54173.2021.9726657
13. Krouska, A., Troussas, C., Sgouropoulou, C.: Fuzzy logic for refining the evaluation of learners' performance in online engineering education. Eur. J. Eng. Technol. Res. **4**(6), 50–56 (2019). https://doi.org/10.24018/ejeng.2019.4.6.1369
14. Troussas, C., Krouska, A., Sgouropoulou, C.: Dynamic detection of learning modalities using fuzzy logic in students' interaction activities. In: Kumar, V., Troussas, C. (eds.) Intelligent Tutoring Systems, pp. 205–213. Springer, Cham (2020)
15. Kassim, R., Johari, J., Rahim, M., Buniyamin, N.: Lecturers' perspective of student online feedback system: a case study (2017). https://doi.org/10.1109/ICEED.2017.8251186
16. Troussas, C., Krouska, A., Sgouropoulou, C.: Impact of social networking for advancing learners' knowledge in E-learning environments. Educ. Inf. Technol. (Dordr) **26**(4), 4285–4305 (2021). https://doi.org/10.1007/s10639-021-10483-6
17. Han, Y., Chen, Y., Wang, R., Wu, J., Gorlatova, M.: Intelli-AR preloading: a learning approach to proactive hologram transmissions in mobile AR. IEEE Internet Things J. **9**(18), 17714–17727 (2022). https://doi.org/10.1109/JIOT.2022.3159554
18. Ito, G., Nakajima, T.: Expanding the interaction space using hand-held-AR with hearing support. In: 2021 Thirteenth International Conference on Mobile Computing and Ubiquitous Network (ICMU), pp. 1–6 (2021). https://doi.org/10.23919/ICMU50196.2021.9638926
19. Kim, S., et al.: Bring store in my room: AR store authoring system for spatial experience in mobile shopping. In: 2022 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct), pp. 654–656 (2022). https://doi.org/10.1109/ISMAR-Adjunct57072.2022.00135

20. Lee, B., Kim, J., Jung, S.-U.: Light-weighted network based human pose estimation for mobile AR service. In: 2020 International Conference on Information and Communication Technology Convergence (ICTC), pp. 1609–1612 (2020). https://doi.org/10.1109/ICTC49870.2020.9289085
21. Linowes, J.: Augmented Reality with Unity AR Foundation: A practical guide to cross-platform AR development with Unity 2020 and later versions. Packt Publishing (2021)
22. Lo, J.-H., Lai, Y.-F.: Effects of incorporating AR-based mobile learning system on elementary school students' perceived usefulness of M-learning. In: 2021 IEEE 3rd Eurasia Conference on Biomedical Engineering, Healthcare and Sustainability (ECBIOS), pp. 169–172 (2021). https://doi.org/10.1109/ECBIOS51820.2021.9510571
23. Petrovic, N., Roblek, V., Khokhobaia, M., Gagnidze, I.: AR-Enabled Mobile Apps to Support Post COVID-19 Tourism (2021). https://doi.org/10.1109/TELSIKS52058.2021.9606335
24. Qiao, X., Ren, P., Dustdar, S., Liu, L., Ma, H., Chen, J.: Web AR: a promising future for mobile augmented reality—state of the art, challenges, and insights. Proc. IEEE **107**(4), 651–666 (2019). https://doi.org/10.1109/JPROC.2019.2895105
25. Vardhan, H., Saxena, A., Dixit, A., Chaudhary, S., Sagar, A.: AR museum: a virtual museum using marker less augmented reality system for mobile devices. In: 2022 3rd International Conference on Issues and Challenges in Intelligent Computing Techniques (ICICT), pp. 1–6 (2022). https://doi.org/10.1109/ICICT55121.2022.10064611
26. Wang, C., Zhao, Y., Guo, J., Pei, L., Wang, Y., Liu, H.: NEAR: the NetEase AR oriented visual inertial dataset. In: 2019 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct), pp. 366–371 (2019). https://doi.org/10.1109/ISMAR-Adjunct.2019.00-10
27. Wang, Y., Wang, Y., Fan, Z.: Current status and prospects of mobile AR applications. In: 2021 International Conference on Culture-oriented Science & Technology (ICCST), pp. 34–37 (2021). https://doi.org/10.1109/ICCST53801.2021.00018
28. Xu, J., Yang, L., Guo, M.: AR mobile video calling system based on WebRTC API. In: 2022 IEEE 5th International Conference on Computer and Communication Engineering Technology (CCET), pp. 110–114 (2022). https://doi.org/10.1109/CCET55412.2022.9906395
29. Zhao, Y., Guo, T.: FUSEDAR: adaptive environment lighting reconstruction for visually coherent mobile AR rendering. In: 2022 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW), pp. 572–573 (2022). https://doi.org/10.1109/VRW55335.2022.00137
30. Zhou, J., Xu, Z., Yan, H., Gao, B., Yang, O., Zhao, Z.: AR creator: a mobile application of logic education based on AR. In: 2020 International Conference on Virtual Reality and Visualization (ICVRV), pp. 379–380 (2020). https://doi.org/10.1109/ICVRV51359.2020.00109
31. Ping, J., Liu, Y., Weng, D.: Study on Mobile AR Guide System to Enhance User Experience in Cultural Heritage Sites (2020). https://doi.org/10.1109/ICVRV51359.2020.00027
32. Medrano, K., Tejada, R., González, B., Juarez, S.: Development of a mobile application with VR and AR to improve the experience of visitors in cultural settings. In: 2021 IEEE CHILEAN Conference on Electrical, Electronics Engineering, Information and Communication Technologies (CHILECON), pp. 1–5 (2021). https://doi.org/10.1109/CHILECON54041.2021.9703083
33. Nguyen, P., Ha, H.-D., Vu, T.-H., Nguyen, Q.-H., Truong, H.-P., Le, H.-S.: Applying VR/AR technology in product advertising to improve user experience. In: 2021 15th International Conference on Advanced Computing and Applications (ACOMP), pp. 201–205 (2021). https://doi.org/10.1109/ACOMP53746.2021.00036

34. Medina-Mota, K.M., López-Morteo, G.A., Cruz-Flores, R.G.: Creation of a game-based augmented learning experience system (GL-XP AR). In: 2022 IEEE Mexican International Conference on Computer Science (ENC), pp. 1–8 (2022). https://doi.org/10.1109/ENC56672.2022.9882939
35. Tang, W., Ge, Q., Zhou, L., Zhu, Q.: Design of spot introduction and user interaction system based on AR augmented reality technology. In: 2018 17th International Symposium on Distributed Computing and Applications for Business Engineering and Science (DCABES), pp. 76–79 (2018). https://doi.org/10.1109/DCABES.2018.00029
36. Leon-Garza, H., Hagras, H., Pena-Rios, A., Owusu, G., Conway, A.: A fuzzy logic based system for cloud-based building information modelling rendering optimization in augmented reality. In: 2020 IEEE International Conference on Fuzzy Systems (FUZZ-IEEE). IEEE (2020). https://doi.org/10.1109/fuzz48607.2020.9177659
37. Papakostas, C., Troussas, C., Krouska, A., Sgouropoulou, C.: Modeling the knowledge of users in an augmented reality-based learning environment using fuzzy logic. In: Krouska, A., Troussas, C., Caro, J. (eds.) Novel & Intelligent Digital Systems: Proceedings of the 2nd International Conference (NiDS 2022), pp. 113–123, Springer, Cham (2023)
38. Pena-Rios, A., Hagras, H., Gardner, M., Owusu, G.: A fuzzy logic based system for geolocated augmented reality field service support. In: 2017 IEEE International Conference on Fuzzy Systems (FUZZ-IEEE). IEEE (2017). https://doi.org/10.1109/fuzz-ieee.2017.8015477
39. Strousopoulos, P., Papakostas, C., Troussas, C., Krouska, A., Mylonas, P., Sgouropoulou, C.: SculptMate: personalizing cultural heritage experience using fuzzy weights. In: Adjunct Proceedings of the 31st ACM Conference on User Modeling, Adaptation and Personalization. ACM (2023). https://doi.org/10.1145/3563359.3596667
40. Papakostas, C., Troussas, C., Sgouropoulou, C.: Review of the literature on AI-enhanced augmented reality in education. In: Papakostas, C., Troussas, C., Sgouropoulou, C. (eds.) Special Topics in Artificial Intelligence and Augmented Reality: The Case of Spatial Intelligence Enhancement, pp. 13–50. Springer, Cham (2024). https://doi.org/10.1007/978-3-031-52005-1_2
41. Papakostas, C., Troussas, C., Krouska, A., Sgouropoulou, C.: PARSAT: fuzzy logic for adaptive spatial ability training in an augmented reality system. Comput. Sci. Inf. Syst. **20**(4) (2023). https://doi.org/10.2298/CSIS230130043P
42. Papakostas, C., Troussas, C., Sgouropoulou, C.: Introduction and overview of AI-enhanced augmented reality in education. In: Papakostas, C., Troussas, C., Sgouropoulou, C. (eds.) Special Topics in Artificial Intelligence and Augmented Reality: The Case of Spatial Intelligence Enhancement, pp. 1–11. Springer, Cham (2024). https://doi.org/10.1007/978-3-031-52005-1_1
43. Papakostas, C., Troussas, C., Krouska, A., Sgouropoulou, C.: On the development of a personalized augmented reality spatial ability training mobile application. In: Frontiers in Artificial Intelligence and Applications, pp. V–VI. IOS Press (2021). https://doi.org/10.3233/FAIA210078