Enhancing Users’ Interactions in Mobile Augmented Reality Systems Through Fuzzy Logic-Based Modelling of Computer Skills

Christos Troussas[a], Christos Papakostas[b] and Cleo Sgouropoulou[c]
Department of Informatics and Computer Engineering, University of West Attica, Egaleo, Greece

Keywords: Fuzzy Logic, Mobile Augmented Reality, Spatial Ability Training, Intelligent Tutoring System, Computer Skills, Feedback, Assistive Messages, Personalization.

Abstract: Mobile augmented reality (AR) systems offer exciting opportunities for blending digital content with the real world. However, engagement in mobile AR environments mainly relies on users’ computer skills, which vary among users and impact their ability to utilize this technology. This research addresses this gap in understanding the influence of users’ computer skills on interactions in mobile AR. In view of the above, this paper presents a fuzzy logic-based model to assess and refine users’ computer skills in the context of mobile AR systems. Modelling the users' computer skills, the system is responsible for providing personalized assistive messages and feedback. These messages are designed to align with the fuzzy weights that have been established, enhancing users’ interactions within the mobile AR environment. The presented approach is integrated in a personalized mobile AR system for spatial ability training. The evaluation results demonstrate a highly positive outlook. A major conclusion of this work is that fuzzy logic modelling has significant potential to enhance user experiences and drive advancements in mobile augmented reality technology.

1 INTRODUCTION

Current research advancements in the field of augmented reality (AR) technology, including mobile AR, have revealed important opportunities for different applications, either for entertainment purposes (e.g., gaming) or education and professional training purposes (Papakostas et al., 2021). Mobile AR offers to users an experience blending digital and physical world, where virtual elements are integrated into the real environment through the use of mobile devices (White et al., 2019). However, despite the potential benefits that mobile AR may offer, there are several challenges for the users, interacting with these systems. These challenges can arise from the lack of familiarity with the technology, limited computer skills, or lack of knowledge regarding the capabilities and functionalities of such systems (Verma et al., 2022).

Indeed, computer skills and knowledge of users can play a crucial role in determining their ability to effectively interact with mobile AR systems. Users who have a higher level of computer skills and knowledge are more likely to easily navigate and utilize the features and functionalities of mobile AR applications. On the other hand, users with limited computer skills may face difficulties in understanding and utilizing the various interaction types or functionalities offered by mobile AR. Therefore, it becomes imperative to model users’ computer skills and knowledge (Irshad et al., 2021; Virvou et al., 2012; Virvou & Troussas, 2011) in order to enhance the way of interaction and overall experience with mobile AR systems.

There are various techniques available to model users' computer skills and knowledge in the context of mobile AR systems. One such technique is fuzzy logic (Campanella, 2021; Krouska et al., 2019; Troussas et al., 2020), which allows for the representation and analysis of imprecise and uncertain information. Fuzzy logic provides a flexible framework for capturing and reasoning about the vagueness and uncertainty associated with users' computer skills. By employing fuzzy logic-based models, it becomes possible to

[a] https://orcid.org/0000-0002-9604-2015
[b] https://orcid.org/0000-0002-5157-347X
[c] https://orcid.org/0000-0001-8173-2622

Troussas, C., Papakostas, C. and Sgouropoulou, C.
Enhancing Users’ Interactions in Mobile Augmented Reality Systems Through Fuzzy Logic-Based Modelling of Computer Skills.
DOI: 10.5220/0012204300003584
In *Proceedings of the 19th International Conference on Web Information Systems and Technologies (WEBIST 2023)*, pages 381-390
ISBN: 978-989-758-672-9; ISSN: 2184-3252

assess users' computer skills on a continuum rather than a binary classification. This enables a more nuanced understanding of users' proficiency levels and allows for personalized interaction experiences in mobile AR systems.

Enhancing user interaction in mobile AR systems can be achieved through the implementation of various techniques, such as providing feedback and delivering informative messages (Kassim et al., 2017; Troussas et al., 2021). Feedback mechanisms can guide users, provide assistance, and offer real-time suggestions to enhance their understanding and utilization of mobile AR features. Messages can be delivered to inform users about specific functionalities, tips, or updates related to the mobile AR application they are using. These enhancements aim to improve the user experience, increase engagement, and facilitate effective interactions in mobile AR environments.

Analysing the literature on mobile AR systems, it is obvious that it has witnessed significant growth throughout the last years. The studies mainly focus on ameliorating the user experience, rendering the interface user-friendly, providing new forms of interaction (Han et al., 2022; Ito & Nakajima, 2021; Kim et al., 2022; Lee et al., 2020; Linowes, 2021; Lo & Lai, 2021; Petrovic et al., 2021; Qiao et al., 2019; Vardhan et al., 2022; C. Wang et al., 2019; Y. Wang et al., 2021; Xu et al., 2022; Zhao & Guo, 2022; Zhou et al., 2020) as well as injecting intelligence in such systems for the purposes of modeling users, knowledge, etc. (Leon Garza et al., 2020; Papakostas et al., 2022, 2023; Peña-Rios et al., 2016, 2017; Strousopoulos et al., 2023). The intelligence in these systems can be achieved using various techniques, including fuzzy logic.

This paper focuses on the investigation of users' computer skills and their impact on interactions within mobile AR systems. Towards this direction, a fuzzy logic-based model is presented to assess and refine users' computer skills in the context of mobile AR. The assessment of computer knowledge in relation to users' interaction with the mobile AR environment was conducted using a questionnaire, being developed by experts in the field and specifically targeted the various aspects of mobile AR interaction. The presented approach is integrated into a personalized mobile AR system for spatial ability training, where assistive messages and feedback are delivered based on the established fuzzy weights. Evaluation results demonstrate a highly positive outlook, highlighting the potential of fuzzy logic modeling to enhance user experiences and drive advancements in mobile AR technology.

2 FUZZY WEIGHTS

Providing assistance to users of mobile augmented reality systems involves considering their computer skills, which is a complex task accompanied by uncertainty. For our study, we utilized a questionnaire developed by a panel of 15 informatics faculty members from public universities. The questionnaire consisted of 10 questions; each assigned a score ranging from lower to higher proficiency. Participants were instructed to select one of the given options for each question, with each option corresponding to a specific grade (e.g., one grade for option A, two grades for option B, etc.); the maximum grading for each participant was set at 40. The questionnaire was designed to assess participants' familiarity and proficiency in various aspects of mobile augmented reality systems. Its questions explored their previous experiences, comfort levels, and knowledge related to AR technology and its integration with other digital tools or platforms.

For instance, it is challenging to definitively classify a user with a computer knowledge test score of 7.5/10 as either good or very good, as both classifications have some level of truth. To address this challenge, fuzzy logic offers a suitable solution. In this approach, learners' computer skills are represented by four fuzzy weights: Novice (N), Basic (B), Advanced (A), and Proficient (P), each characterized by trapezoidal membership functions (Table 1, Figure 1). These functions are defined by four boundary values (a1, a2, a3, a4), where the degree of membership gradually increases from 0 to 1 between a1 and a2, remains constant at 1 between a2 and a3, and decreases from 1 to 0 between a3 and a4. Trapezoidal membership functions were chosen because they accurately capture the interval where students' scores fully belong to a specific knowledge category.

As previously mentioned, the current level of computer knowledge of a user in AR interactions is represented using the membership functions discussed earlier. These membership functions define the values of the fuzzy weights, ranging from 0 to 1. A value of 1 for the knowledge level indicates that the user has achieved mastery in the domain and possesses comprehensive knowledge. Consequently, the total value of each divided fuzzy set represents the knowledge level of a domain learning unit and sums up to 1, as shown by the equation $\mu_N(x) + \mu_B(x) + \mu_A(x) + \mu_P(x) = 1$.

Table 1: Membership functions.

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)
$\mu_P(x) = \begin{cases} \frac{x-35}{2} & 35 < x < 37 \\ 1 & 37 \leq x \leq 40 \\ 0 & x > 40 \end{cases}$

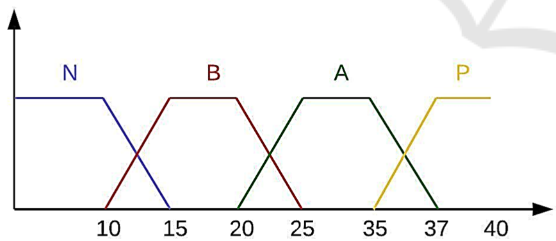

Figure 1: Schemes of Fuzzy Weights.

The determination of the fuzzy weights and the thresholds for their membership functions was carried out by 15 faculty members from public universities specializing in informatics. These faculty members were asked to provide descriptive definitions of learners' computer knowledge levels throughout the learning process, as well as the ranges of achievement describing each knowledge level. With over 12 years of experience in university contexts, the faculty members possess the expertise necessary to accurately depict users' computer knowledge skills.

3 ASSISTIVE MESSAGES DELIVERY

In this section, we provide a comprehensive overview of the assistive messages and feedback that are specifically customized to align with the previously established fuzzy weights. These personalized messages are delivered to users at different stages of their interaction with the mobile AR environment, aiming to enhance their overall experience and facilitate their engagement with the technology.

Each fuzzy weight encompasses several categories of assistive messages (see subsections 3.1.1, 3.1.2, 3.1.3, 3.2.1, 3.2.2, 3.2.3, 3.3.1, 3.3.2, 3.3.3, 3.4.1, 3.4.2, 3.4.3, 3.4.4) that can be provided to the user in a random way. For example, under the novice user category, there exist message categories such as "Getting Started", "Navigation and Exploration", and "Help and Guidance". Once the system determines the user's fuzzy weight, it is responsible for selecting the most suitable category for delivery on each occasion. To accomplish this, the system utilizes an if-then algorithmic approach that takes into account the user's interaction history, as well as the current task or context. Within each category, the system randomly selects a message to deliver to the specific user, ensuring a personalized and tailored experience.

3.1 Feedback to Novice Users

Novice users, characterized by their limited or no prior experience with AR systems, necessitate comprehensive guidance and step-by-step instructions. The personalized feedback messages designed for this user group fall into three primary categories.

3.1.1 Category: Getting Started

Novices are welcomed to the world of augmented reality and introduced to basic features through step-by-step instructions. Instructions include tapping on virtual objects for interaction and maintaining an appropriate distance for optimal engagement. An illustration of a message is: "To interact with virtual objects, simply tap on them. Try tapping on the floating cube to see it respond!".

3.1.2 Category: Navigation and Exploration

Novices are guided on navigation within the AR environment, encouraging them to explore and discover virtual content. An emphasis is placed on the use of the on-screen guide and user manual as sources of assistance when needed. An illustration of a message is: “To navigate through the AR environment, swipe left, right, up, or down to move around and discover more virtual content”.

3.1.3 Category: Help and Guidance

Novices are reassured that they can refer to the user guide for detailed explanations and helpful tips. The availability of in-app support is highlighted, promoting self-paced learning and confidence building. An illustration of a message is: “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”.

3.2 Feedback to Basic Users

Basic users have acquired some familiarity with AR systems and mobile devices, allowing them to perform common tasks. Nevertheless, they may require occasional assistance or reference materials for more advanced features. The personalized feedback messages tailored to this user group encompass three primary categories.

3.2.1 Category: Enhancing Interaction

Basic users are congratulated for their familiarity with augmented reality and encouraged to enhance their interaction skills. They are guided to experiment with different gestures and tapping techniques for various virtual object interactions. An illustration of a message is: “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”.

3.2.2 Category: Exploring Advanced Features

Basic users are prompted to explore the settings menu to customize preferences, thus delving into more advanced features. Recommendations include adjusting sensitivity settings and experimenting with additional features like voice commands. An illustration of a message is: “Adjust the sensitivity of your device’s motion tracking to ensure a smoother and more immersive augmented reality experience”.

3.2.3 Category: Assistance and Resources

Basic users are advised to refer to the user guide for detailed explanations and troubleshooting tips, particularly when encountering challenges. The availability of a help section within the app, comprising FAQs and video tutorials, is emphasized to provide valuable insights and guidance. An illustration of a message is: “If you encounter any challenges or have questions about specific features, refer to the user guide for detailed explanations and troubleshooting tips”.

3.3 Feedback to Advanced Users

Advanced users demonstrate a comprehensive understanding of AR systems and are proficient in utilizing their features. These users can navigate complex interfaces, customize settings, interact seamlessly with virtual objects, and troubleshoot common issues. The personalized feedback messages for advanced users span three primary categories.

3.3.1 Category: Mastering Advanced Interactions

Advanced users are acknowledged for their mastery of the basics and encouraged to explore complex interactions confidently. Suggestions include experimenting with advanced gestures and exploring hand or body tracking options for more natural interactions. An illustration of a message is: “Consider exploring hand tracking or body tracking options for a more immersive and natural interaction with the augmented reality environment”.

3.3.2 Category: Customization and Optimization

Advanced users are guided toward customizing and optimizing their AR experience.
They are encouraged to explore advanced settings, including shaders, level of detail (LoD), and occlusion culling, to maximize performance and visual quality. An illustration of a message is: “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”.

3.3.3 Category: Troubleshooting and Support

Advanced users are recognized for their troubleshooting skills and encouraged to share their knowledge with the community. Recommendations include staying updated with software releases and reaching out to dedicated support teams for more complex issues. An illustration of a message is: “Stay updated with the latest software updates and firmware releases to ensure compatibility, stability, and access to new features and improvements".

3.4 Feedback to Proficient Users

Proficient users are highly skilled and experienced, possessing in-depth knowledge of advanced features and the ability to optimize system performance. They may even have the capacity to develop or customize their own augmented reality experiences. The personalized feedback messages tailored to this user group encompass four primary categories.

3.4.1 Category: Unleashing Creative Potential

Proficient users are welcomed as AR experts, with an emphasis on their valuable knowledge and skills.
They are encouraged to leverage their expertise to push the boundaries of augmented reality and develop unique, interactive narratives or games. An illustration of a message is: "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".

3.4.2 Category: Performance Optimization and Customization

Proficient users are prompted to optimize system performance and visual quality. Suggestions include fine-tuning advanced settings, experimenting with lighting and shadow techniques, and implementing optimization strategies. An illustration of a message is: "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".

3.4.3 Category: Collaboration and Sharing

Proficient users are encouraged to share their expertise with the AR community through forums, online communities, or developer conferences. They are advised to consider publishing their AR experiences or apps on dedicated platforms to reach a wider audience. An illustration of a message is: "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.".

3.4.4 Category: Cutting-Edge Research and Innovation

Proficient users are recognized as pioneers of AR innovation. They are encouraged to stay informed about the latest advancements, explore cutting-edge areas, and contribute to the field through research, development, and mentoring. An illustration of a message is: "You are at the forefront of AR innovation! Stay informed about the latest advancements, research papers, and emerging technologies to continue expanding your expertise".

4 EVALUATION

In this section, we present the evaluation of the system's performance and effectiveness.

4.1 Descriptive Analysis

The evaluation process spanned an entire academic semester and involved the concept of spatial ability training tutoring in the context of the undergraduate course "Educational Technologies and IT Didactics" of a public university located in the capital city of the country. The evaluation included the participation of 80 undergraduate students. It is worth noting that the measurements of gender and age were obtained from a randomly selected sample and did not influence the research findings.

Table 2: Questionnaire.

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?

The questionnaire (Table 2) aims to assess participants' knowledge, experience, and comfort level with augmented reality (AR) technology. The questionnaire consists of four questions that cover various aspects of AR, including knowledge, usage, proficiency, familiarity with virtual objects, comfort with mobile devices, experience in creating AR experiences, familiarity with different AR technologies, troubleshooting skills, and integration of AR with digital tools. The responses will provide valuable insights into the participants' understanding and proficiency in AR, which can help in identifying areas for improvement and tailoring future AR-related initiatives to their needs.

To conduct a descriptive analysis of the questionnaire responses, the authors summarized the data by calculating the frequency for each question (Figure 2).

Based on the responses from the participants, the descriptive analysis reveals interesting insights about their knowledge, experience, and comfort level with AR technology.

The descriptive analysis of the effectiveness of feedback messages regarding AR usage and proficiency reveals that the majority of participants found the feedback to be helpful. Combining the “extremely helpful” and “very helpful” categories, 53.75% of participants rated the feedback as highly beneficial. This indicates that the feedback messages provided valuable insights and guidance for improving participants' understanding and skills in AR. However, there is room for improvement, as 18.75% of participants expressed lower levels of effectiveness. This highlights the importance of tailoring feedback to address individual areas of improvement and accommodating varying levels of proficiency.

Analyzing the effectiveness of personalized feedback messages in addressing specific areas of improvement, the results indicate that a considerable number of participants (62.5%) felt that the feedback addressed their needs either “very well” or “well”. This demonstrates that the personalized feedback messages were effective in targeting specific areas of improvement and enhancing participants' understanding and skills in AR. However, it is essential to address the concerns of the participants who found the feedback to be less effective (15%) to ensure a comprehensive and tailored approach.

Regarding the user interface of the AR application, the analysis shows that the majority of participants (71.25%) rated it as either “excellent” or “good”. This indicates a positive evaluation of the application's design and usability, suggesting that the user interface provided a satisfactory experience for most participants. However, the ratings for the user interface were not uniformly positive, with 10% expressing lower satisfaction levels. This highlights the importance of continuous improvement and refining the user interface to cater to a wide range of user preferences and needs.

Overall, the participants' ratings for their overall user experience with the AR application are positive. The majority (68.75%) rated their experience as either “excellent” or “good”. This suggests that the AR application provided a positive user experience

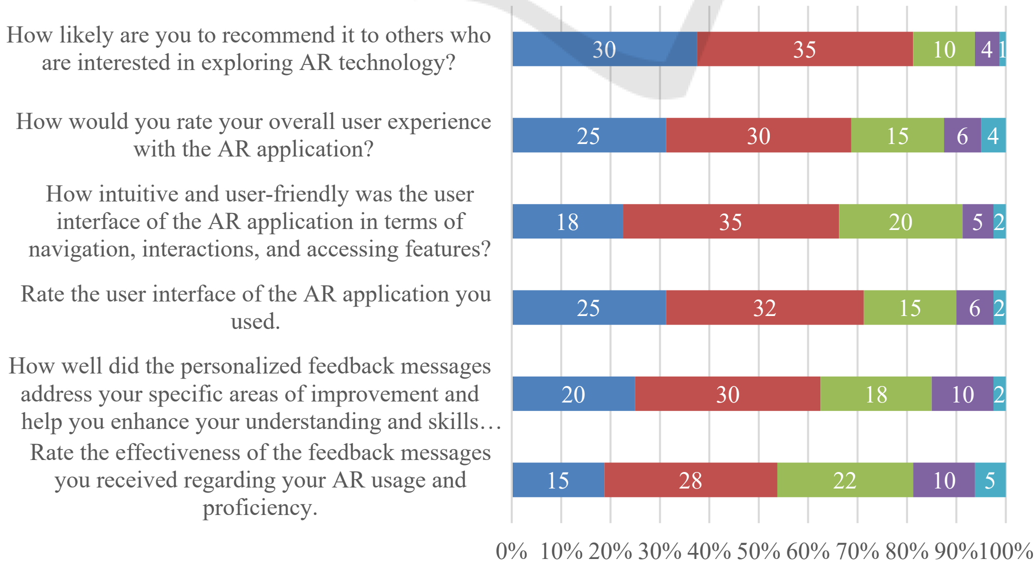

Figure 2: Frequency of the answers in stacked-bar mode.

for most participants, indicating that it met their expectations in terms of performance, usability, and enjoyment. However, a small percentage of participants (12.5%) rated their experience as average or poor, indicating areas where the application could be improved to enhance user satisfaction.

Regarding the likelihood of recommending the AR application to others interested in exploring AR technology, the analysis reveals a positive inclination among participants. A significant majority (81.25%) expressed a likelihood of recommending the application, either "very likely" or "likely". This high recommendation potential indicates that participants perceived the AR application as valuable and beneficial, indicating a positive overall impression. However, it is crucial to address the concerns of participants who expressed reluctance or neutrality (6.25%) to maximize the application's potential reach and impact.

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

4.2 Statistical Analysis

The instructors divided the population into two groups, each consisting of 40 students. One group, known as the experimental group, was instructed to utilize an AR application that included feedback messaging. In contrast, the second group, referred to as the control group, did not have access to the feedback generation module.

Adaptive feedback messaging plays a significant role in evaluating the effectiveness of an intelligent tutoring system that incorporates personalized feedback through fuzzy logic. In this regard, a questionnaire was administered to assess users' perceptions of the system's ability to personalize the feedback.

To determine whether there is a statistically significant difference in personalized messages between students who used the AR application with personalized feedback and those who did not, a *t*-test analysis was conducted. The *t*-test analysis involved the following steps:

- Definition of the null hypothesis (H0) and alternative hypothesis (H1) based on the research question and objectives.
- Selection of the significance level (alpha) to determine the threshold for accepting or rejecting the null hypothesis. We used .05 value for alpha.
- Data collection from both the experimental group and the control group.
- Calculation of the mean scores of the two groups separately, representing the perceptions of personalized messages.
- Calculation of the variance for each group, which provides an indication of the spread or variability in the data.
- Calculation of the *t*-test, which compares the means of the two groups and assesses whether the difference is statistically significant.
- Determination of the *p*-value associated with the calculated *t*-statistic. The critical value is compared to the significance level (alpha) to determine if the null hypothesis should be rejected or not.
- Interpretation of the results: If the *p*-value is less than the significance level, the null hypothesis is rejected, indicating a statistically significant difference in personalized messages between the two groups. On the other hand, if the *p*-value is greater than the significance level, the null hypothesis is not rejected, suggesting no statistically significant difference between the groups.

At the end of the semester, both the experimental and control groups were given a questionnaire to complete. The questionnaire utilized a 5-point Likert scale, where participants could indicate their agreement or disagreement on a scale from 1 (strongly disagree) to 5 (strongly agree).

To conduct a *t*-test analysis between the experimental group and the control group regarding the effectiveness of the feedback messages received regarding AR usage and proficiency, we compared the ratings provided by the two groups. The *t*-test determined if there is a significant difference between the means of the two groups.

First, we set up the null hypothesis (H0) and the alternative hypothesis (H1):

H0: There is no significant difference in the effectiveness of feedback messages between the experimental and control groups.

H1: There is a significant difference in the effectiveness of feedback messages between the experimental and control groups.

Next, we performed a *t*-test analysis using the ratings provided by the two groups, calculating the *t*-value and *p*-value (Table 3).

Table 3: *t*-test results.

	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	

Based on the *t*-value and degrees of freedom, we can determine the statistical significance of the results. The *p*-value is below the predetermined significance level of .05, so we reject the null hypothesis and conclude that there is a significant difference in the effectiveness of feedback messages between the experimental and control groups.

The *t*-test analysis reveals a *t*-statistic of 11.400. With 186 degrees of freedom, the *p*-value for a one-tailed test is less than 0.001. This indicates that the observed difference in the effectiveness of feedback messages between the two groups is statistically significant.

The null hypothesis (H0) assumes no significant difference between the two groups, while the alternative hypothesis (H1) suggests a significant difference. Given that the *p*-value is less than the chosen significance level, we reject the null hypothesis and conclude that there is a significant difference in the effectiveness of feedback messages between the experimental and control groups.

Furthermore, the *t*-test results provide evidence that the mean effectiveness rating for the experimental group (M = 4.129) is significantly higher than the mean effectiveness rating for the control group (M = 3.083). This suggests that the feedback messages received by the participants in the experimental group were more effective in enhancing their understanding and skills in AR compared to the control group.

5 CONCLUSIONS

This paper presents a novel approach for enhancing users' interactions in mobile augmented reality systems through the application of fuzzy logic-based modelling of computer skills. The proposed fuzzy logic model allows for personalized delivery of assistive messages and feedback tailored to individual users' computer skills, enabling them to navigate and utilize mobile AR environments effectively.

The evaluation results demonstrate the effectiveness of the approach, emphasizing the potential of fuzzy logic modelling to refine users' interactions and pave the way for future advancements in mobile AR technology.

Future plans involve the development of a hybrid algorithmic approach that combines fuzzy logic with machine learning techniques. We will explore how this approach will affect accuracy and adaptability in tailoring messages to individual users' needs and preferences.

REFERENCES

Campanella, P. (2021). Neuro-Fuzzy Learning in Context Educative. *2021 19th International Conference on Emerging ELearning Technologies and Applications (ICETA)*, 58–69. https://doi.org/10.1109/ICETA54173.2021.9726657

Han, Y., Chen, Y., Wang, R., Wu, J., & Gorlatova, M. (2022). Intelli-AR Preloading: A Learning Approach to Proactive Hologram Transmissions in Mobile AR. *IEEE Internet of Things Journal*, *9*(18), 17714–17727. https://doi.org/10.1109/JIOT.2022.3159554

Irshad, S., Rambli, D. R. A., & Sulaiman, S. (2021). Design and Implementation of User Experience Model for Augmented Reality Systems. *Proceedings of the 18th International Conference on Advances in Mobile Computing & Multimedia*, 48–57. https://doi.org/10.1145/3428690.3429169

Ito, G., & Nakajima, T. (2021). Expanding the Interaction Space using Hand-Held-AR with Hearing Support. *2021 Thirteenth International Conference on Mobile Computing and Ubiquitous Network (ICMU)*, 1–6. https://doi.org/10.23919/ICMU50196.2021.9638926

Kassim, R., Johari, J., Rahim, M., & Buniyamin, N. (2017). *Lecturers' perspective of student online feedback system: A case study*. https://doi.org/10.1109/ICEED.2017.8251186

Kim, S., Jang, H., Oh, K. T., Oh, S. Y., Kim, D., Woo, W., Lee, J., Ahn, J., & Yoon, S. H. (2022). Bring Store in My Room: AR Store Authoring System for Spatial Experience in Mobile Shopping. *2022 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct)*, 654–656. https://doi.org/10.1109/ISMAR-Adjunct57072.2022.00135

Krouska, A., Troussas, C., & Sgouropoulou, C. (2019). Fuzzy logic for refining the evaluation of learners' performance in online engineering education. *European*

Journal of Engineering and Technology Research, *4*(6), 50–56. https://doi.org/10.24018/ejeng.2019.4.6.1369

Lee, B., Kim, J., & Jung, S.-U. (2020). Light-weighted Network based Human Pose Estimation for Mobile AR Service. *2020 International Conference on Information and Communication Technology Convergence (ICTC)*, 1609–1612. https://doi.org/10.1109/ICTC49870.2020.9289085

Leon Garza, H., Hagras, H., Peña-Rios, A., Owusu, G., & Conway, A. (2020). *A Fuzzy Logic Based System for Cloud-based Building Information Modelling Rendering Optimization in Augmented Reality*. https://doi.org/10.1109/FUZZ48607.2020.9177659

Linowes, J. (2021). *Augmented Reality with Unity AR Foundation: A practical guide to cross-platform AR development with Unity 2020 and later versions*. Packt Publishing.

Lo, J.-H., & Lai, Y.-F. (2021). Effects of Incorporating AR-based Mobile Learning System on Elementary School Students’ Perceived Usefulness of M-learning. *2021 IEEE 3rd Eurasia Conference on Biomedical Engineering, Healthcare and Sustainability (ECBIOS)*, 169–172. https://doi.org/10.1109/ECBIOS51820.2021.9510571

Papakostas, C., Troussas, C., Krouska, A., & Sgouropoulou, C. (2021). Exploration of Augmented Reality in Spatial Abilities Training: A Systematic Literature Review for the Last Decade. *Informatics in Education*, *20*(1), 107–130. https://doi.org/10.15388/infedu.2021.06

Papakostas, C., Troussas, C., Krouska, A., & Sgouropoulou, C. (2022). Personalization of the Learning Path within an Augmented Reality Spatial Ability Training Application Based on Fuzzy Weights. *Sensors*, *22*(18). https://doi.org/10.3390/s22187059

Papakostas, C., Troussas, C., Krouska, A., & Sgouropoulou, C. (2023). Modeling the Knowledge of Users in an Augmented Reality-Based Learning Environment Using Fuzzy Logic. In A. Krouska, C. Troussas, & J. Caro (Eds.), *Novel & Intelligent Digital Systems: Proceedings of the 2nd International Conference (NiDS 2022)* (pp. 113–123). Springer International Publishing. https://doi.org/10.1007/978-3-031-17601-2_12

Peña-Rios, A., Hagras, H., Gardner, M., & Owusu, G. (2017). *A fuzzy logic based system for geolocated augmented reality field service support*. https://doi.org/10.1109/FUZZ-IEEE.2017.8015477

Peña-Rios, A., Hagras, H., Owusu, G., & Gardner, M. (2016). *A Fuzzy Logic based system for Mixed Reality assistance of remote workforce*. https://doi.org/10.1109/FUZZ-IEEE.2016.7737716

Petrovic, N., Roblek, V., Khokhobaia, M., & Gagnidze, I. (2021). *AR-Enabled Mobile Apps to Support Post COVID-19 Tourism*. https://doi.org/10.1109/TELSIKS52058.2021.9606335

Qiao, X., Ren, P., Dustdar, S., Liu, L., Ma, H., & Chen, J. (2019). Web AR: A Promising Future for Mobile Augmented Reality—State of the Art, Challenges, and Insights. *Proceedings of the IEEE*, *107*(4), 651–666. https://doi.org/10.1109/JPROC.2019.2895105

Strousopoulos, P., Papakostas, C., Troussas, C., Krouska, A., Mylonas, P., & Sgouropoulou, C. (2023). SculptMate: Personalizing Cultural Heritage Experience Using Fuzzy Weights. *Adjunct Proceedings of the 31st ACM Conference on User Modeling, Adaptation and Personalization*, 397–407. https://doi.org/10.1145/3563359.3596667

Troussas, C., Krouska, A., & Sgouropoulou, C. (2020). Dynamic Detection of Learning Modalities Using Fuzzy Logic in Students' Interaction Activities. In V. Kumar & C. Troussas (Eds.), *Intelligent Tutoring Systems* (pp. 205–213). Springer International Publishing. https://doi.org/10.1007/978-3-030-49663-0_24

Troussas, C., Krouska, A., & Sgouropoulou, C. (2021). Impact of social networking for advancing learners' knowledge in E-learning environments. *Education and Information Technologies*, *26*(4), 4285–4305. https://doi.org/10.1007/s10639-021-10483-6

Vardhan, H., Saxena, A., Dixit, A., Chaudhary, S., & Sagar, A. (2022). AR Museum: A Virtual Museum using Marker less Augmented Reality System for Mobile Devices. *2022 3rd International Conference on Issues and Challenges in Intelligent Computing Techniques (ICICT)*, 1–6. https://doi.org/10.1109/ICICT55121.2022.10064611

Verma, A., Purohit, P., Thornton, T., & Lamsal, K. (2022). An examination of skill requirements for augmented reality and virtual reality job advertisements. *Industry and Higher Education*, *37*(1), 46–57. https://doi.org/10.1177/09504222221109104

Virvou, M., & Troussas, C. (2011). Web-based student modeling for learning multiple languages. *International Conference on Information Society (i-Society 2011)*, 423–428. https://doi.org/10.1109/i-Society18435.2011.5978484

Virvou, M., Troussas, C., Caro, J., & Espinosa, K. J. (2012). User Modeling for Language Learning in Facebook. In P. Sojka, A. Horák, I. Kopeček, & K. Pala (Eds.), *Text, Speech and Dialogue* (pp. 345–352). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-642-32790-2_42

Wang, C., Zhao, Y., Guo, J., Pei, L., Wang, Y., & Liu, H. (2019). NEAR: The NetEase AR Oriented Visual Inertial Dataset. *2019 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct)*, 366–371. https://doi.org/10.1109/ISMAR-Adjunct.2019.00-10

Wang, Y., Wang, Y., & Fan, Z. (2021). Current Status and Prospects of Mobile AR Applications. *2021 International Conference on Culture-Oriented Science & Technology (ICCST)*, 34–37. https://doi.org/10.1109/ICCST 53801.2021.00018

White, G., Cabrera, C., Palade, A., & Clarke, S. (2019). Augmented reality in IoT. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, *11434 LNCS*, 149–160. https://doi.org/10.1007/978-3-030-17642-6_13

Xu, J., Yang, L., & Guo, M. (2022). AR Mobile Video Calling System Based on WebRTC API. *2022 IEEE 5th*

International Conference on Computer and Communication Engineering Technology (CCET), 110–114. https://doi.org/10.1109/CCET55412.2022.9906395

Zhao, Y., & Guo, T. (2022). FUSEDAR: Adaptive Environment Lighting Reconstruction for Visually Coherent Mobile AR Rendering. *2022 IEEE Conference on Virtual Reality and 3D User Interfaces Abstracts and Workshops (VRW)*, 572–573. https://doi.org/10.1109/VRW55335.2022.00137

Zhou, J., Xu, Z., Yan, H., Gao, B., Yang, O., & Zhao, Z. (2020). AR Creator: A Mobile Application of Logic Education Based on AR. *2020 International Conference on Virtual Reality and Visualization (ICVRV)*, 379–380. https://doi.org/10.1109/ICVRV51359.2020.00109