2022 IEEE International Symposium on Mixed and Augmented Reality Adjunct (ISMAR-Adjunct)

User Retention of Mobile Augmented Reality for Cultural Heritage Learning

Ningning Xu, Yue Li*, Jie Lin, Lingyun Yu, and Hai-Ning Liang
Department of Computing, School of Advanced Technology, Xi'an Jiaotong-Liverpool University

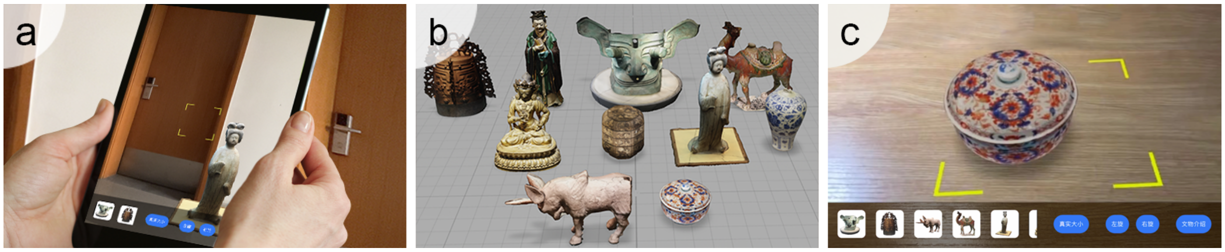

Figure 1: Cultural heritage learning with mobile AR: (a) a user viewing an artifact's actual size; (b) ten artifacts used in the mobile AR application; (c) a screenshot of the mobile AR application deployed on an iPad.

Abstract

Mobile Augmented Reality (AR) is becoming increasingly affordable and popular with the constantly improving computing power of mobile devices and the popularity of smartphones and tablets. In this paper, we present a user study that investigates user retention of mobile AR in cultural heritage learning. We developed a mobile AR application that allows users to observe 3D models of museum artifacts and learn about their culture and history. Participants achieved a knowledge retention rate of 78.21%, indicating the positive effects of mobile AR on cultural heritage learning. We performed a structural equation modeling analysis (N=50) to investigate the effects of usability, satisfaction, emotional attachment, focus of attention, and flow experience on user retention of mobile AR. The analysis results confirmed that user satisfaction and flow experience positively affect user retention. Usability and focus of attention contribute positively to user satisfaction and flow experience respectively.

Keywords: augmented reality, mobile AR, user retention, cultural heritage, learning

Index Terms: Human-centered computing—Human computer interaction (HCI)—Interaction paradigms—Mixed/augmented reality

1 Introduction

Augmented Reality (AR) combines virtual 3D objects with the physical reality to bring more enriching interactive experiences to people [1]. Mobile AR applications render virtual 3D objects on top of the real-world image captured by the camera, thus giving the impression that virtual objects appear in the real environment through the mobile display. The interactive experience of mobile AR applications has great potential for use in many fields, including education, art, entertainment, medical treatment, and tourism [2]. Recent studies [3, 4] have shown that AR applications can increase students' motivation to learn, improve their interaction in teaching and learning activities, and ultimately bring up their academic performances.

Visiting museums is a vital way to learn about culture and history. However, museum artifacts exhibited in glass cases have limited interactions to engage visitors in learning about cultural heritage. AR technology can enhance the interactivity of learning [5], and many mobile AR applications have been developed for this purpose.

*Corresponding Author. Email: yue.li@xjtlu.edu.cn

We are interested in the factors influencing user retention of mobile AR, namely, the continued use of this method to learn cultural heritage. Previous studies indicated that the experience of flow and satisfaction were the main factors influencing users' intention to continue participating in an activity [6, 7]. In addition, mobile AR applications allow students to feel the flow experience and to be more focused on learning [8]. In previous research, emotional attachment and usability were also identified as influencing factors for user retention. Thus, we ask this research question: *what factors affect mobile AR user retention for cultural heritage learning?* Our analysis demonstrated that usability has a positive effect on satisfaction while focus of attention has a positive effect on flow experience, which further influences satisfaction. The user retention of mobile AR use is directly influenced by satisfaction and flow experience.

Our research makes three main contributions. First, we present a mobile AR application to support cultural heritage learning and provide empirical evidence of its positive effect on learning effectiveness. Second, we analyze and explain the relationship between factors that affect the user retention of mobile AR in cultural heritage learning. Finally, we discuss the implications of our research and provide suggestions for researchers, museum practitioners, and mobile AR developers on future directions.

2 Related Work

2.1 Mobile Augmented Reality

Mobile augmented reality (AR) has been widely adopted in different domains for visualizations and interactions. The ability to present information in 3D space allows it to build complex applications that benefit a variety of scenarios, such as games, learning, and cultural heritage [9]. The development of mobile AR applications allows developers to design interactive user experiences with the real-world environment through mobile devices, touchscreen controls, and multimedia, which is technologically acceptable, easy to learn, and affords a vast variety of information.

One of the main strengths of AR is the ability to simulate information that is difficult to experience in reality, such as those from a particular time and space to build physical and emotional connections. This has particular benefits to the museum context. For example, Ryffel et al. [10] showed an AR application that displayed multiple layers of the paintings and allowed users to modify the colors of each layer and create their own work. Similarly, Chang et al. [11] presented an AR application that helped visitors learn how to appreciate paintings in museums. These examples demonstrated that mobile AR can support visitors' creative ideas and help them better understand artwork in museums.

2771-1110/22/$31.00 ©2022 IEEE
DOI 10.1109/ISMAR-Adjunct57072.2022.00095

2.2 Learning Effectiveness of Mobile AR

Research related to learning effectiveness has focused on comparing different training methods and learning media to see which method or medium is more helpful for people to learn. Beers and Bowde [12] conducted measured participants' knowledge levels before and after knowledge acquisition. They applied pre-tests and post-tests to compare the learning effectiveness of different learning methods. Rondon et al. [13] explored whether the computer game-based learning method is more effective than the traditional learning method in helping students learn biology-related knowledge. They found no significant difference in short-term learning, but the traditional learning approach was advantageous for long-term knowledge retention.

In previous studies, AR-based systems have been shown advantageous in learning effectiveness compared to conventional training methods. Lam et al. [14] compared the effects of stereoscopic-based AR applications and paper-based manuals on learning effectiveness. They asked participants to learn how to disassemble the PlayStation 3 game console during the experiment. The experiment consisted of a pre-test and a post-test, which examined how much the participants knew about the console, and how many of the disassemble steps they still remembered. The results of the experiment showed that the AR-based learning method resulted in better learning performances and was more popular among the participants. The 3D animations used in the AR application illustrated the installation and disassembly of the machine, making it easier for users to understand each step than textual instructions.

2.3 Mobile AR and Cultural Heritage Learning

Previous research indicated that AR systems can effectively assist vocabulary learning [15], enhance knowledge memorization [16], and facilitate teenagers' learning of artifact information [17]. These studies have shown that it is desired for the design of mobile AR learning systems to achieve satisfying learning experiences and high user retention, which indicates users' willingness to continue using the medium to learn.

Previous research has shown several advantages of mobile AR for cultural institutions. First, it makes use of visitors' own devices and does not require investing in hardware infrastructures [18]. Second, AR as an interactive technology can provide supplementary information that facilitates and motivates users' learning in museum exhibitions [19]. Third, mobile AR could support creative work in museums, such as gameplay and customized gifts that incorporate both digital content and physical exhibits [20], contributing to the social value of interactions.

Outside the museum space, users can also use AR to view the digital replicas of artifacts and engage in highly interactive learning activities [21, 9]. Mobile AR allows museum collections to be accessed by a wider audience, breaking the constraints of time and space. The combined use of digital visualization in mobile applications and interactive manipulations of physical objects was found acceptable to users in learning about cultural heritage [22].

Despite AR's strengths, learning with AR was also found to have some limitations. For example, users sometimes struggle to gauge the actual size of digital museum artifacts [23]. In addition, digital content in mobile applications may result in significant information overload [24]. They also suggested that when users are highly engaged and immersed, they would lose track of time, leading to a higher learning cost to some extent.

3 Research Model and Hypotheses

Emotional Attachment. Emotional attachment refers to the emotional connection with applications based on users' personal feelings, such as curiosity and accomplishment [25]. Salar et al. investigated the factors influencing users' interest in using AR technology and found that emotional attachment should be sustained to support users' focus of attention in AR. Therefore, we propose that Emotional Attachment has a positive effect on Focus of Attention (**H1**).

Focus of Attention. Focus of attention has long been recognized as a prerequisite for transforming into a flow experience [26]. Harris et al. [27] suggested that an external focus would lead to promoting flow experience in simulated driving, and contribute to positive performance states. Therefore, we put forward the following hypothesis: Focus of Attention has a positive effect on Flow Experience (**H2**).

Flow Experience. Flow experience was found to associate with satisfaction, such as job satisfaction [28] and life satisfaction [29]. Previous studies also verified that flow experience is a significant predictor of satisfaction with online learning [30, 7]. This leads to our **H3**: Flow Experience has a positive effect on Satisfaction.

Usability. Usability contributes to the quality of use [31]. Previous research found that usability positively affects user satisfaction in e-business [32], and there is a positive correlation between usability and satisfaction in the mobile phone industry [33]. It was also found to have a positive effect on user satisfaction with online information acquisition [34]. Thus, we hypothesize that Usability has a positive effect on Satisfaction (**H4**).

Satisfaction. Satisfaction was found to be a crucial factor in retention. Hong et al. [35] indicated that users' satisfaction is the key to continued use of mobile internet. Previous research also showed a positive correlation between users' satisfaction and continuous intention to use [36]. For example, Levy [37] suggested that user satisfaction is a significant factor in students' dropout decisions in e-learning, showing the positive effect of satisfaction on retention. Similarly, Lee and Choi [7] found that students' satisfaction has a significant direct effect on retention of technology use. Therefore, we propose that Satisfaction has a positive effect on Retention (**H5**).

Retention. Aside from the positive effect of satisfaction on retention, flow experience was also found to contribute to learner persistence [38]. Lee and Choi [7] found that flow experience has a significant positive effect on student retention. Thus, we propose **H6**: Flow Experience has a positive effect on Retention.

We summarize the proposed research model in Figure 2.

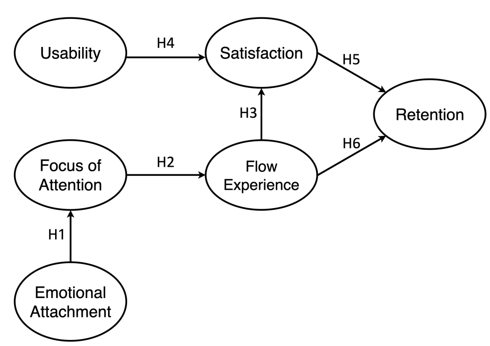

Figure 2: Our proposed model on user retention of mobile AR.

4 System and Study Design

4.1 Mobile AR Application

Apple's iPad is one of the most popular learning mobile devices in education [39]. Therefore, we developed a mobile AR application[1] using the Swift programming language and Apple's AR development libraries, RealityKit 2 and ARKit 5. The application was deployed on an iPad Mini 6.

Figure 3 shows some screenshots of the mobile AR application. When the mobile AR application is opened, users can swipe left and

[1]Demo: https://youtu.be/oF4u5KoAZmA

right to view different artifacts in the bottom left corner of the user interface, where thumbnails of the artifacts are shown. After tapping on an artifact thumbnail, users will see a scan box that indicates that the application is recognizing a plane where the model can be placed (see Figure 3a). Users can move the iPad to recognize a flat surface, such as the desktop or the floor. After a plane is recognized, the recognized area is indicated by a yellow rectangle (see Figure 3b). Users can tap on the tick icon to confirm the plane or the cross icon to cancel and restart the plane recognition. Once confirmed, the selected artifact will be displayed in the recognized area (see Figure 3c).

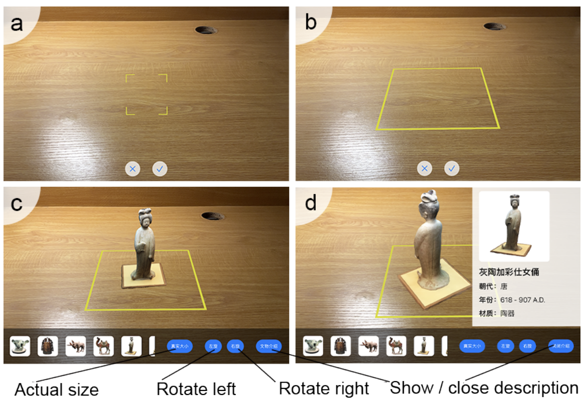

Figure 3: Some screenshots of the mobile AR application, showing (a) recognizing a plane, (b) a plane found, (c) an artifact is placed; (d) a rotated view with artifact information.

Users can zoom in and out of the model by pinching with two fingers and move the model with one finger. The bottom right corner of the AR application has some function buttons. Users can scale the virtual artifact to the actual size by tapping on the "Actual Size" button. Figure 1a shows the model of the *Pottery Figure of A Standing Lady* being scaled to the actual size of 75.5 cm. Users can tap on the "Rotate left" and "Rotate right" buttons to rotate the model clockwise or counterclockwise. By tapping on the "Show description" button, users can see a detailed description of the artifact, including its name, period and year, material, size, museum collection information and description of culture and history (see Figure 3d). There is no need to repeat steps (a) and (b) when viewing other artifacts if the recognized area is within the camera range.

4.2 Procedures and Measures

At the beginning of each experiment, we briefed the participant on the experiment's purpose and procedure and collected their consent. This was followed by a tutorial on the mobile AR application. Then, participants filled in a pre-experiment questionnaire about demographics and a knowledge check questionnaire about five information dimensions of the artifacts: history (period and year), material, size, location (museum collection information), and detailed descriptions of the culture and history. Specifically, there are four questions for each artifact. Each question has four choices, with the default one being "I don't know", one correct answer, and two distractors. This yielded scores of either 0 (incorrect) or 1 (correct) for each question, thus the average score for each artifact ranged from 0 to 4.

After using the mobile AR application, participants completed the knowledge check again and filled in the learning experience questionnaire (see the demo video for more details). Each question was rated from 1 (strongly disagree) to 7 (strongly agree). In the end, we conducted a short semi-structured interview to collect qualitative feedback on cultural heritage learning with mobile AR. Each experiment lasted about 40 minutes. Similar to the previous studies of long-term knowledge retention [40], we invited participants to do the knowledge check again after three days. In total, we obtained a sample of 50 participants (24 males, 26 females) aged between 18 to 26 (M = 22.58, SD = 1.88). All participants voluntarily signed up for the experiment. There were no monetary incentives, but free drinks and snacks were provided. The study was categorized as Low-Risk Research (LRR) research, conducted according to the guidelines regulating LRR projects, and approved by the University Ethics Committee at Xi'an Jiaotong-Liverpool University.

5 Results

5.1 Learning Effectiveness

We used IBM SPSS Statistics for statistical analysis. The average correct rates for the three knowledge checks are 12.58%, 63.08%, and 50.08%. A Friedman test showed that there was a statistically significant difference in the performance on three knowledge checks (χ^2 (2) = 40.621, p <0.001, see Figure 4). Post-hoc analysis with Wilcoxon signed-rank tests was conducted with Bonferroni correction applied, resulting in a significance level set at p <0.017. The rankings for the two post-experiment knowledge checks were significantly higher than the pre-experiment knowledge check (p <0.001).

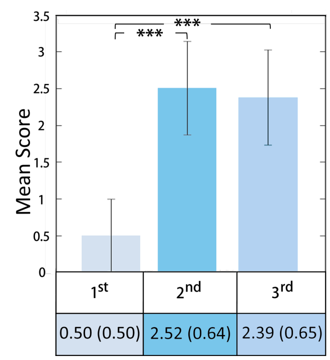

Figure 4: Means (with standard deviations) of knowledge checks.

To calculate the knowledge retention rate, we eliminated the false positives and checked only the questions that participants got correct in both post-experiment knowledge checks. Participants achieved a knowledge retention rate of 78.21%, indicating the positive effects of mobile AR on cultural heritage learning.

5.2 Model Reliability and Validity

We used SmartPLS to conduct confirmatory factor analysis to verify the reliability and validity of the structural equation model.

Reliability refers to the consistency of results when the same test is repeatedly taken on the same subject with the same method or at different test times. The standard reliability tests are Cronbach's Alpha (CA) and Composite Reliability (CR). The closer the value of CA is to 1, the higher the internal consistency reliability of the questionnaire. CR is considered as a preferable evaluation of internal consistency compared to CA because it preserves the standardized loadings of the observed variables. The accepted threshold value of CR is 0.6. An initial investigation of the reliability showed that the CA and CR values for Emotional Attachment did not reach the acceptable threshold. Therefore, this construct was dropped from the model.

We examined the outer loadings of each questionnaire item. The outer loading determines an item's absolute contribution to its assigned construct, which is expected to be greater than 0.7. After removing the unacceptable questionnaire items, we obtained the revised model. The CA and CR values of the revised model reached the acceptable threshold (see Table 1).

Table 1: Construct reliability and validity of the model.

Construct	CA	CR	AVE
FA	0.892	0.892	0.736
FE	0.902	0.901	0.694
U	0.863	0.864	0.614
S	0.888	0.888	0.664
R	0.849	0.850	0.653

Validity measures the degree of difference between the data obtained from the questionnaire measurement and the ideal value, examining whether the questionnaire is accurately measuring the intended constructs. The structural validity of the model is divided into two parts: convergent validity and discriminant validity.

Convergent Validity.

We evaluated the convergent validity of the model by measuring the Average Variance Extracted (AVE). The convergent validity of the model is acceptable (see Table 1).

Discriminatory Validity. The traditional way to assess discriminatory validity is to check the Fornell and Larcker criterion and the cross-loadings of indicators [41]. For each indicator and its corresponding construct, the outer loading is larger than the cross-loading with other constructs, which indicates that the discriminant validity of the model is also acceptable.

5.3 Model Validation

We confirm that the measurement model is reliable and valid. The validation of the structural model involves measuring the predictive relevance of the model and the relationship between the constructs. We evaluated the structural model with the path coefficient (β), T-statistics value, coefficient of determination (R^2), and the Goodness-of-Fit (GoF) index. Figure 5 shows the model validation results.

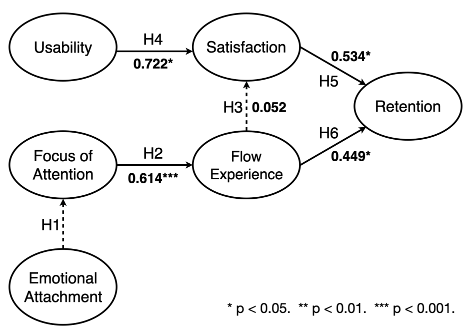

Figure 5: Assessment of the structural equation model and proposed hypotheses.

Path coefficients. The path coefficients' magnitude, sign, and significance are examined. The sign of the path coefficient indicates whether two latent variables are positively or negatively correlated, which is crucial for our hypothesis testing. The magnitude of the path coefficient is related to the strength of the relationship between the latent variables. The larger the path coefficient, the stronger the relationship between the two latent variables.

We dropped Emotional Attachment due to its low reliability; as such, **H1** is not supported. The effect of Focus of Attention on Flow Experience was significant (β=0.614, T=4.316, p<0.000); thus, **H2** is supported. In addition, the effect of Usability on Satisfaction was significant (β=0.722, T=2.651, p<0.01); therefore, **H4** is supported. Significant positive effects were shown for Satisfaction (β=0.449, T=2.699, p<0.01) and Flow Experience (β=0.449, T=2.699, p<0.01) on Retention; **H5** and **H6** are supported. Nevertheless, **H3** is not supported due to the lack of significant effect of Flow Experience on Satisfaction (β=0.052, T=0.191, p>0.05).

Table 2: The coefficient of determination and its effect level.

Endogenous Latent Variables	R^2	Level
FE	0.377	weak
S	0.580	moderate
R	0.776	substantial

The coefficient of determination R^2. The coefficient of determination of the structural model provides an assessment of model prediction accuracy by measuring the overall effect size and explained variance of the endogenous latent variables. R^2 values of 0.25, 0.50, and 0.75 are regarded as weak, moderate, and substantial effects. In this study, the coefficients of determination of each endogenous latent variable are shown in Table 2. The coefficient of determination of Retention is 0.776, which indicates that the Flow Experience and Satisfaction substantially explain 77.6% of the variance in Retention. The coefficient of determination for Satisfaction is 0.58, moderately explaining its variance as influenced by Usability and Flow Experience. 37.7% of the variance of Flow Experience is explained by Focus of Attention.

Goodness-of-Fit index. Goodness-of-Fit (GoF) is a global fit measure for PLS path modeling. It is calculated by the geometric mean of the mean of AVE and average R^2: GoF $= \sqrt{\overline{\text{AVE}} * \overline{R^2}}$. From Table 1 and 2, the mean value of AVE is 0.6722 and the mean value of R^2 is 0.5777. Substituting these two results into the equation, the GoF value of our model is 0.6232, which exceeds the 0.36 threshold value. This indicates that the experimental data fit the model substantially and has large predictive power.

6 Discussion

6.1 Learning Effectiveness of Mobile AR

Participants showed good short-term and long-term learning performances as indicated by the two post-experiment knowledge checks and the retention rates. In terms of qualitative feedback, participants mentioned how they favor interactive experiences in museum learning: *"I always go to museums when I travel. I like interactive devices because they are more interesting."* Participants recognized that AR technology provides an interactive way of learning cultural heritage, and allows them to interact with the vivid display of 3D models. Many participants commented that it was a great experience to see the actual sizes of artifacts and them being blended in with the real environment. Some also liked the view perspective changes allowed in mobile AR.

Several potential improvements can be seen from participants' comments. Participants found some factual information, such as artifact sizes and museum locations more difficult to remember than material and history. Some suggested the use of visualization elements, such as a map of artifact locations. Participants also wanted the key information to be more visible in the text descriptions: *"Reading the text descriptions is a bit boring. It would be better if the key information is highlighted"*. In addition, we see a connection between users' interest and willingness to learn. For example, *"I only checked on the Tri-colored Camel, the Bronze Mask and the Palace Museum one, because I want to confirm what I already knew"*; and *"I checked on what I am interested in. Those are also the parts I remember"*. Some participants reported that they were motivated to learn because they wanted to perform well in the knowledge checks.

Overall, we received positive feedback on mobile AR for cultural heritage learning. Most participants highlighted the benefits of the 3D displays and the interactivity. Using mobile AR to attract users, especially young people in learning about cultural heritage is a good starting point. The interview comments suggested that users' learning can be better supported if text descriptions of artifacts are visualized in mobile AR applications.

6.2 User Retention of Mobile AR

Our investigation showed that user satisfaction and flow experience have positive impacts on user retention of mobile AR. The usability of mobile an AR application positively affects user satisfaction, and the focus of attention contributes positively to the flow experience. These findings suggest that the design of mobile AR applications should set usability goals such as ease of use and good utility to ensure user satisfaction. In addition, the use of mobile AR for learning activities should support users' focused attention that will lead to the flow experience and ultimately user retention.

Flow experience was identified as an influencing factor of satisfaction in previous work [7], but this is not supported in our study. It is likely that in the context of cultural heritage learning, flow experience is not directly associated with satisfaction. Users can become willing to reuse the mobile AR application for learning because they are satisfied with the characteristics of mobile AR, such as the 3D interactivity; they will also reuse it if they are focused and engaged in the learning of cultural heritage content.

The impact of satisfaction demonstrates the importance of the mobile AR medium (3D representations, touchscreen interactions, etc.). Meanwhile, the influence of flow experience shows the significance of the content (museum artifacts, their looks, descriptions, histories, cultures, etc.). Both the medium and the content are crucial in sustaining user retention of mobile AR in cultural heritage learning.

6.3 Key Findings and Lessons Learned

Here we summarize three key findings and the lessons learned from our study.

First, the knowledge check performances showed that mobile AR is effective in supporting cultural heritage learning. Users' learning could be further improved if text descriptions of artifacts are visualized.

Second, user retention of mobile AR is directly influenced by their satisfaction, which mediates the effect of usability. Future design of mobile AR applications should prioritize usability to improve user satisfaction and user retention.

Third, user retention of mobile AR is directly influenced by the flow experience, which mediates the effect of focus of attention. In this regard, our study showed that conducting knowledge checks can motivate users to focus and learn about cultural heritage.

6.4 Limitations and Future Work

This research has the following limitations. First, our experiment mainly involved participants aged 18 to 26. They have more experience using digital technologies and could learn and memorize things relatively fast. Our sample primarily represents young adults, but they are by no means the only age group for mobile AR. Evaluations with users across a wider age group and from different backgrounds are needed in future work. Second, the mobile AR application design in this work mainly took advantage of the 3D representations and basic touchscreen interactions. Multimedia (such as audios and videos) or visualization elements (such as timelines and maps) were not fully utilized in the design of the mobile AR application. Despite this, the significant effect of mobile AR on learning effectiveness and knowledge retention was confirmed. It is anticipated that the results can be further enhanced by an optimized mobile AR design that makes appropriate use of multimedia and visualization elements. Finally, in the structural equation modeling analysis, we were unable to investigate the effect of emotional attachment on focus of attention due to the unsatisfying construct reliability. One possible reason is that our sample size was at the minimum requirement of PLS-SEM analysis. Nevertheless, the overall model is of good fit and shows substantial explanation of the factors influencing user retention of mobile AR in cultural heritage learning.

7 Conclusion

In this paper, we present a study that investigates users' learning effectiveness with mobile AR and the factors that affect user retention of mobile AR for cultural heritage learning. Participants' knowledge check performances were significantly higher after using the mobile AR application, and there is no significant difference between the two post-tests for short-term and long-term learning. We performed structural equation modeling and confirmed that user satisfaction and flow experience positively affect user retention. Usability and focus of attention contribute positively to user satisfaction and flow experience respectively. Based on these findings, we offer some suggestions for the future design of mobile AR applications for cultural heritage learning: to prioritize usability to improve user satisfaction and user retention; to support users' focus of attention and flow experience, such as by conducting knowledge checks; and to leverage visualization elements to support visual learning styles.

Acknowledgments

This research is supported in part by the Natural Science Foundation of the Jiangsu Higher Education Institutions of China, and the Xi'an Jiaotong-Liverpool University (XJTLU) Research Development Fund (RDF-20-02-47) and Teaching Development Fund (TDF20/21-R22-142).

References

[1] R. T. Azuma, "A Survey of Augmented Reality," *Presence: Teleoperators and Virtual Environments*, aug 1997.

[2] Y. Chen, Q. Wang, H. Chen, X. Song, H. Tang, and M. Tian, "An overview of augmented reality technology," in *Journal of Physics: Conference Series*, vol. 1237, no. 2. IOP Publishing, 2019, p. 022082.

[3] T. Khan, K. Johnston, and J. Ophoff, "The impact of an augmented reality application on learning motivation of students," *Advances in Human-Computer Interaction*, vol. 2019, 2019.

[4] Y. C. Chen, "Effect of mobile augmented reality on learning performance, motivation, and math anxiety in a math course," *Journal of Educational Computing Research*, 2019.

[5] A. Hassan and H. Ramkissoon, "Augmented reality application to museum visitor experiences," *Visitor management in tourist destinations*, vol. 3, p. 117, 2016.

[6] C.-C. Chang, "Examining users' intention to continue using social network games: A flow experience perspective," *Telematics and Informatics*, vol. 30, no. 4, pp. 311–321, 2013.

[7] Y. Lee and J. Choi, "A structural equation model of predictors of online learning retention," *The Internet and Higher Education*, vol. 16, pp. 36–42, 2013.

[8] D. M. Bressler and A. M. Bodzin, "Investigating flow experience and scientific practices during a mobile serious educational game," *Journal of Science Education and Technology*, vol. 25, no. 5, pp. 795–805, 2016.

[9] Y. Li, L. Yu, and H.-N. Liang, "CubeMuseum: An Augmented Reality Prototype of Embodied Virtual Museum," in *ISMAR 2021: IEEE International Symposium on Mixed and Augmented Reality*, Bari, Italy, 2021.

[10] M. Ryffel, F. Zünd, Y. Aksoy, A. Marra, M. Nitti, T. O. Aydın, and B. Sumner, "Ar museum: A mobile augmented reality application for interactive painting recoloring," in *Multi Conference on Computer Science and Information Systems*, 2017.

[11] K.-E. Chang, C.-T. Chang, H.-T. Hou, Y.-T. Sung, H.-L. Chao, and C.-M. Lee, "Development and behavioral pattern analysis of a mobile guide system with augmented reality for painting appreciation instruction in an art museum," *Computers & education*, vol. 71, pp. 185–197, 2014.

[12] G. W. Beers and S. Bowden, "The effect of teaching method on long-term knowledge retention," *Journal of Nursing Education*, vol. 44, no. 11, pp. 511–514, 2005.

[13] S. Rondon, F. C. Sassi, and C. R. F. de Andrade, "Computer game-based and traditional learning method: a comparison regarding students' knowledge retention," *BMC medical education*, vol. 13, no. 1, pp. 1–8, 2013.

[14] M. C. Lam, M. J. Sadik, and N. F. Elias, "The effect of paper-based manual and stereoscopic-based mobile augmented reality systems on knowledge retention," *Virtual Reality*, 2021.

[15] A. Ibrahim, B. Huynh, J. Downey, T. Hollerer, D. Chun, and J. O'Donovan, "ARbis Pictus: A study of vocabulary learning with augmented reality," *IEEE Transactions on Visualization and Computer Graphics*, vol. 24, no. 11, pp. 2867–2874, 2018.

[16] D. Agostini, "Je-LKS HERITAGE USING MOBILE," *Journal of e-Learning and Knowledge Society*, pp. 115–128, 2016.

[17] V. Cesário, A. Coelho, and V. Nisi, ""This is nice but that is childish": Teenagers evaluate museum-based digital experiences developed by cultural heritage professionals," *CHI PLAY 2019 - Extended Abstracts of the Annual Symposium on Computer-Human Interaction in Play*, no. October, 2019.

[18] A. Damala, P. Cubaud, A. Bationo, P. Houlier, and I. Marchal, "Bridging the gap between the digital and the physical," 2008.

[19] C. Pollalis, A. Gilvin, L. Westendorf, L. Futami, I. Virgilio, D. Hsiao, and O. Shaer, "ARtLens: Enhancing museum visitors' engagement with African art," *DIS 2018 - Companion Publication of the 2018 Designing Interactive Systems Conference*, pp. 195–200, 2018.

[20] B. Koleva, J. Spence, S. Benford, H. Kwon, H. Schnädelbach, E. Thorn, W. Preston, A. Hazzard, C. Greenhalgh, M. Adams, J. R. Farr, N. Tandavanitj, A. Angus, and G. Lane, "Designing Hybrid Gifts," *ACM Transactions on Computer-Human Interaction*, vol. 27, no. 5, 2020.

[21] A. Angelopoulou, D. Economou, V. Bouki, A. Psarrou, L. Jin, C. Pritchard, and F. Kolyda, "Mobile augmented reality for cultural heritage," *Lecture Notes of the Institute for Computer Sciences, Social-Informatics and Telecommunications Engineering*, vol. 93 LNICS, pp. 15–22, 2012.

[22] Y. Li, E. Ch'Ng, S. Cai, and S. See, "Multiuser Interaction with Hybrid VR and AR for Cultural Heritage Objects," *Proceedings of the 2018 3rd Digital Heritage International Congress, Digital Heritage 2018*, 2018.

[23] C. Pollalis, E. J. Minor, L. Westendorf, W. Fahnbulleh, I. Virgilio, A. L. Kun, and O. Shaer, "Evaluating learning with tangible and virtual representations of archaeological artifacts," *TEI 2018 - Proceedings of the 12th International Conference on Tangible, Embedded, and Embodied Interaction*, 2018.

[24] H. Petrie, M. K. Othman, and C. Power, "Smartphone Guide Technology in Cultural Spaces: Measuring Visitor Experience with an iPhone Multimedia Guide in Shakespeare's Church," *International Journal of Human-Computer Interaction*, 2017.

[25] R. Salar, F. Arici, S. Caliklar, and R. M. Yilmaz, "A model for augmented reality immersion experiences of university students studying in science education," *Journal of Science Education and Technology*, vol. 29, no. 2, pp. 257–271, 2020.

[26] M. Csikszentmihalyi, *Flow: The Psychology of Optimal Experience*, 01 1990.

[27] D. J. Harris, S. J. Vine, and M. R. Wilson, "An external focus of attention promotes flow experience during simulated driving," *European Journal of Sport Science*, pp. 1–10, 2018.

[28] R. Maeran and F. Cangiano, "Flow experience and job characteristics: Analyzing the role of flow in job satisfaction," *TPM - Testing, Psychometrics, Methodology in Applied Psychology*, vol. 20, no. 1, pp. 13–26, 2013.

[29] Y. Mao, R. Yang, M. Bonaiuto, J. Ma, and L. Harmat, "Can flow alleviate anxiety? The roles of academic self-efficacy and self-esteem in building psychological sustainability and resilience," *Sustainability (Switzerland)*, 2020.

[30] D. Rossin, Y. Ro, B. Klein, and Y. Guo, "The effects of flow on learning outcomes in an online information management course," *Journal of Information Systems Education*, 2009.

[31] N. Bevan, "Usability is quality of use," *Advances in Human Factorsergonomics*, vol. 20, pp. 349–354, 1995.

[32] M. Xue and P. Harker, "Customer efficiency concept and its impact on e-business management," *Journal of Service Research*, 07 2001.

[33] J. Heo, D.-H. Ham, S. Park, C. Song, and W. C. Yoon, "A framework for evaluating the usability of mobile phones based on multi-level, hierarchical model of usability factors," *Interacting with Computers*, vol. 21, no. 4, pp. 263–275, 2009.

[34] S.-M. Kim and J.-Y. Oh, "Health information acquisition online and its influence on intention to visit a medical institution offline," *Information Research*, vol. 16, 12 2011.

[35] S. J. Hong, J. Y. Thong, and K. Y. Tam, "Understanding continued information technology usage behavior: A comparison of three models in the context of mobile internet," *Decision Support Systems*, vol. 42, no. 3, pp. 1819–1834, 2006.

[36] R. Kumar, "An empirical study on service quality perceptions and continuance intention in mobile banking context in india," 2012.

[37] Y. Levy, "Comparing dropouts and persistence in e-learning courses." 01 2004, pp. 245–254.

[38] Y. J. Joo, S. Joung, and W. J. Sim, "Structural relationships among internal locus of control, institutional support, flow, and learner persistence in cyber universities," *Computers in Human Behavior*, 2011, web 2.0 in Travel and Tourism: Empowering and Changing the Role of Travelers.

[39] D. Sari, E. Lanham, and L. Pan, "The usefulness metrics of the most popular ereader used by higher education students," *Issues in Informing Science and Information Technology*, 2015.

[40] F. Bermúdez-Rattoni, "Studies of short-term avoidance memory – neural plasticity and memory: From genes to brain imaging," *CRC Press*, 2007.

[41] C. Fornell and D. F. Larcker, "Evaluating structural equation models with unobservable variables and measurement error," *Journal of marketing research*, vol. 18, no. 1, pp. 39–50, 1981.