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Comparing VR and AR in Cultural Heritage Active Learning: A Study Based on the Stimulus-Organism-Response Model and the Engagement Theory

Jiayi Zhao[1 †], Jiachen Liang[1 †], Yue Li[1 ‡], Cheng Zhang[2] and Yiping Dong[2]

[1]School of Advanced Technology, Xi'an Jiaotong-Liverpool University, Suzhou, China
[2]Design School, Xi'an Jiaotong-Liverpool University, Suzhou, China

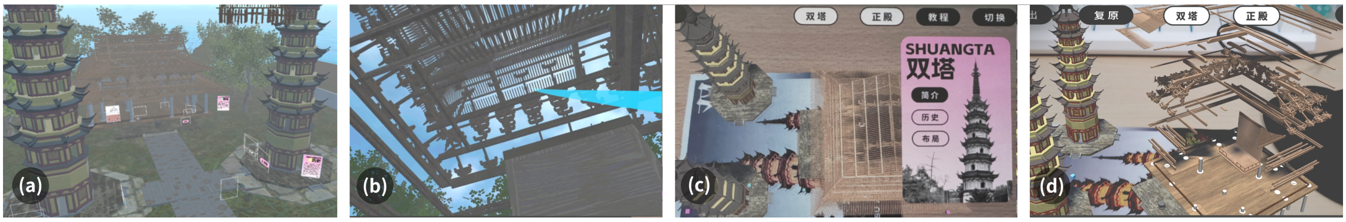

Figure 1: *The demonstration of (a) virtual reality environment for the heritage site; (b) the interaction with 3D model of the main hall in VR environment; (c) augmented reality environment for the heritage site; (d) the interaction with 3D model of the main hall in AR environment.*

Abstract

With the rapid advancement of immersive technologies, Virtual Reality (VR) and Augmented Reality (AR) have emerged as powerful tools for enhancing cultural heritage experiences. These technologies offer opportunities to engage learners through interactive and rich content, transforming how cultural knowledge is disseminated and understood. In this study, we developed two systems - one in VR with a head-mounted display and the other in AR with a mobile device for cultural heritage exploration. By employing a comprehensive survey with 70 responses, we explored the determinants of active learning within two systems. The results showed that the effects of interactivity and content richness on active learning are mediated by cognitive engagement toward both VR and AR systems. Our findings contribute valuable insights to the field of technology-mediated learning and provide practical guidelines for optimizing immersive cultural heritage experiences through targeted design strategies, highlighting the potential gaps in content design optimization.

CCS Concepts

• ***Human-centered computing*** → ***HCI design and evaluation methods; User studies;***

1. Introduction

In recent years, immersive technologies such as virtual reality (VR) and augmented reality (AR) have gained considerable attention and seen rapid advancements. These technologies are now widely applied across various fields, including cultural tourism. Cultural heritage (CH) institutions and stakeholders have increasingly adopted VR and AR to develop virtual tours, enabling immersive experiences for individuals who cannot access heritage sites in person [BKPW]. These innovations provide alternative ways for people to engage with cultural heritage, overcoming physical limitations and enhancing public access to cultural content. At the same time, the preservation of CH continues to face serious challenges, such as environmental degradation, urban development, aging infrastructure, and limited conservation resources. In this context, VR and AR offer promising solutions. By creating interactive and dynamic representations of heritage sites, these technologies can support both heritage presentation and public awareness of preservation efforts [Add]. Prior studies have demonstrated the potential of VR and AR to enrich the visitor experience by fostering immersive and interactive encounters [RFA, TWJTD]. These technologies have also been shown to encourage deeper exploration of cultural heritage and to increase visitor participation [Nur].

† These authors contributed equally to this work.
‡ Corresponding author.

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A core mission of CH institutions is the dissemination of cultural knowledge to the wider public. In the context of postmodern tourism, CH items play a crucial role in disseminating cultural knowledge and fostering public awareness. Active learning, which emphasizes learner participation and hands-on experience, aligns well with the interactive potential of immersive technologies. VR and AR can support this educational approach by placing users in rich, exploratory environments that encourage curiosity and engagement [BEMDS]. Immersive experiences not only provide real-time information and guided interactions but also introduce novel forms of display that enhance user communication and sustained interest. Research has shown that greater content richness leads to higher levels of engagement and communicative behavior in learning environments [LS]. Riva et al. further emphasize that content richness shapes user perception and affective connection to virtual environments [RWW]. Building on these insights, this study identifies interactivity and content richness as key stimuli influencing users' perceptions of virtual heritage tours. It examines how these factors affect affective, behavioral, and cognitive engagement within VR and AR environments.

To explore these dynamics, we developed two immersive heritage experiences (one in VR and one in AR) focused on a heritage site *Shuangta*. Drawing on the Stimulus-Organism-Response (SOR) model and engagement theory, this research investigates the impact of interactivity and content richness (stimuli) on user engagement (organism), and how this in turn affects active learning outcomes (response). Learning outcomes were also assessed by comparing knowledge gains between user groups. The findings offer both theoretical insights and practical guidance for designing effective, immersive educational tools using emerging technologies.

2. Literature Review

2.1. Active Learning in Cultural Heritage

Active learning emphasizes learner autonomy, critical thinking, and meaningful engagement, encouraging exploration and personal connection over passive information intake [MWN]. Immersive technologies like VR and AR create highly interactive environments that support this approach, enabling users to intuitively engage with complex historical content [GAK*]. These tools are especially valuable in cultural heritage, where they reconstruct past environments and deepen educational outcomes. A notable example is the Bergen-Belsen Memorial project [BWR*], which used tablets and panoramic installations to guide visitors through historical narratives. The study showed increased interest and improved understanding among participants, demonstrating how immersive, active learning can enhance cultural engagement and reflection.

2.2. Virtual Reality and Augmented Reality in Cultural Heritage

Virtual tourism, a form of "alternative tourism," enables destination exploration without physical travel [TKND]. VR offers fully immersive 3D environments that engage users through multisensory input [XLZ*23], and has been widely adopted across industries due to its ability to influence psychological and behavioral responses more effectively than traditional media [LH]. In tourism, VR facilitates remote visits to cultural sites, enriching the sense of presence and authenticity [NDB]. AR overlays digital information onto the real world, integrating virtual elements with physical environments to enhance on-site experiences [LZLD25]. AR has been shown to improve user engagement and behavioral intention in tourism settings [XLL*24], with mobile accessibility accelerating its adoption [XLS*23]. Both VR and AR offer immersive, interactive experiences that deepen user engagement with cultural heritage [TWJTD]. However, their experiential characteristics differ, warranting separate evaluation in heritage contexts to better understand their unique impacts on user engagement and learning [RFH*].

2.3. Theoretical Framework

The **Stimulus-Organism-Response (SOR)** model is a comprehensive framework developed by Mehrabian and Russel in 1974 for understanding how environmental factors influence individuals' internal states and behaviors [CSK]. It consists of three key components: **Stimulus (S)**, which refers to external environmental factors that affect or act upon individuals and organisms [DSH]. **Organism (O)**, encompassing the internal structures and processes that mediate interactions between stimuli and responses [LH]. **Response (R)** represents individuals' attitude reactions and behaviors to internal and external stimuli [WCL*]. According to the SOR model, environmental stimuli shape users' internal states, which in turn lead to specific behavioral responses. This framework has been widely adopted in tourism and consumer research to examine how virtual environments affect user experience and decision-making [DSH, KLJ].

Engagement theory arises from educational research in electronic and distance learning contexts [KLJ, Shn]. It emphasizes the importance of learners' active involvement in the learning process and identifies three dimensions of engagement: affective, behavioral, and cognitive [Zyn]. Among them, **affective engagement** includes learners' interest in what they are learning, things, and emotional experiences. Positive emotions lead to better learning outcomes as well as behavioral and cognitive engagement, while negative emotions have a negative impact on all of them [PGTP02, PEM09]. **Behavioral engagement** includes observable actions such as participating in discussions, asking questions, or interacting with learning materials. **Cognitive engagement** involves deeper mental processes such as analyzing, reflecting, and applying knowledge, indicating the extent to which learners invest attention and effort in the learning task [RPR, Pos].

Together, the SOR model and engagement theory provide a valuable lens for examining how immersive technologies, as environmental stimuli, influence users' internal states and behaviors, particularly in the context of cultural heritage learning.

3. Research Model and Hypotheses

3.1. Research Model

Based on the SOR model and engagement theory, this project aims to explore the key factors influencing active learning towards cultural heritage (CH) contexts and to compare the impacts on VR and

AR technologies. Ben-Eliyahu et al. [BEMDS] integrated the three dimensions of engagement (i.e., affective, behavioral, and cognitive) into models of learning motivation and engagement. Their findings demonstrated that these dimensions are closely linked to learning outcomes and provide a meaningful basis for assessing active learning. Similarly, Guo et al. [GLS*] applied the SOR framework to immersive environments, showing its effectiveness in capturing how environmental stimuli, such as those in VR and AR settings, influence users' psychological and cognitive responses.

Buiding on these foundations, the research model proposed in this study (see Figure 2) examines how two environmental stimuli, interaction (IN) and content richness (CR), influence the three forms of user engagement: affective engagement (AE), behavioral engagement (BE), and cognitive engagement (CE). In turn, the model explores how each engagement dimension contributes to active learning (AL) outcomes.

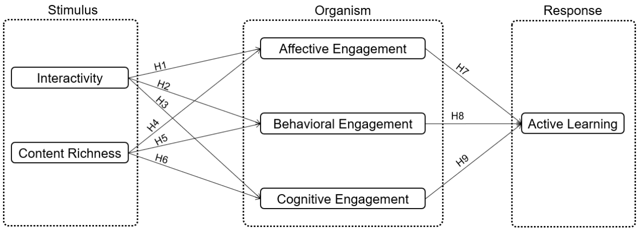


Figure 2: *The proposed research model, based on the Stimulus-Organism-Response (SOR) model and engagement theory, contains six constructs.*

3.2. Hypotheses

In this study, we defined and elaborated six constructs: Interactivity (IN), Content Richness (CR), Affective Engagement (AE), Behavioral Engagement (BE), Cognitive Engagement (CE), and Active Learning (AL). We summarize our hypotheses in Table 1.

Table 1: *Measurement items of the constructs.*

	Description
H1	Interactivity positively influences users' affective engagement in VR (H1a) / AR (H1b).
H2	Interactivity positively influences users' behavioral engagement in VR (H2a) / AR (H2b).
H3	Interactivity positively influences users' cognitive engagement in VR (H3a) / AR (H3b).
H4	Content richness positively influences users' affective engagement in VR (H4a) / AR (H4b).
H5	Content richness positively influences users' behavioral engagement in VR (H5a) / AR (H5b).
H6	Content richness positively influences users' cognitive engagement in VR (H6a) / AR (H6b).
H7	Affective engagement positively influences users' active learning in VR (H7a) / AR (H7b).
H8	Behavioral engagement influences users' active learning in VR (H8a) / AR (H8b).
H9	Cognitive engagement positively influences users' active learning in VR (H9a) / AR (H9b).

Interactivity. Interactivity is a defining characteristic of immersive technologies, influencing users' affective, behavioral, and cognitive engagement. In VR, high levels of interactivity and presence enhance emotional responses [MMLGA], while in AR, perceived interactivity shapes affective reactions and behavioral intentions [Jav]. Park et al. [PLK] similarly highlight the role of interactive engagement in eliciting emotional involvement. Based on these findings, it is expected that the interactivity of immersive technologies affects users' affective engagement (**H1**). Interactivity also impacts behavioral engagement by encouraging more frequent and deeper user interactions. Studies show that well-designed interactive systems increase user activity across platforms and environments [Kum], with interface design and usability further influencing engagement behaviors [AHH]. Thus, we propose interactivity to have a positive impact on behavioral engagement (**H2**). In addition, immersive interactions have been shown to enhance cognitive processing. Realistic, interactive environments stimulate mental effort and improve performance [Gao], supporting our final interactivity hypothesis: interactivity has a positive impact on cognitive engagement (**H3**).

Content Richness. Content richness refers to the depth, diversity, and quality of information presented in an immersive environment. Rich content can enhance users' emotional involvement by offering detailed, meaningful, and contextually relevant information. Riva et al. [RWW] argue that richer content increases emotional resonance and immersion. Similarly, Lan et al. [LS] found that users are more communicative and engaged when exposed to rich informational environments. Hence, it is proposed that content richness would have an influence on affective engagement (**H4**). Rich content can also stimulate user interaction and participation. Systems offering layered, dynamic content tend to increase behavioral engagement by prompting more exploratory and participatory behaviors [YK]. Therefore, it is expected that the content richness of immersive technologies affects users' behavioral engagement (**H5**). Cognitively, content richness supports deeper understanding by encouraging learners to analyze, connect, and interpret information. Prior studies highlight its role in facilitating knowledge construction and critical thinking [RWW, LS]. Therefore, this project expects content richness to have a positive impact on cognitive engagement (**H6**).

Affective Engagement. It is defined by emotional involvement and interest, and has been shown to positively influence motivation and attention, thereby enhancing learning outcomes [PGTP02]. Jones et al.'s study [jb] found that affective learning environments that trigger emotional responses significantly increase engagement and motivation, leading to more effective knowledge acquisition and retention. Thus, it is considered that affective factors play an important role in enhancing the active learning environment (**H7**).

Behavioral Engagement. Behavioral engagement, reflected in participation and task involvement, directly correlates with deeper learning through repeated interaction and practice [PC]. Research indicates that behavioral factors are also levers for active learning and that applying information is necessary in conjunction with facilitating interaction [Sri]. Thus, it is expected that behavioral factors in active learning environments increase behavioral engagement and learning outcomes (**H8**).

Cognitive Engagement. Cognitive engagement involves users' active participation in the learning process through the use of strategic, metacognitive, and self-regulation skills to promote understanding. Harris and Bacon's [HB] study demonstrated that active learning is more effective at improving analytical, evaluative, and creative skills than passive instruction, which proves that active learning strategies are directly related to the improvement of higher-order cognitive skills. Thus, we propose that active learning strategies are directly related to the improvement of higher-order cognitive abilities (**H9**).

4. System Design and Implementation

To investigate the factors that may influence active learning, we conducted design practices around a local thousand-year-old heritage site (i.e., *Shuangta*). Two systems were developed based on VR and AR technologies, respectively. The 3D models (including twin pagodas and the main hall) are proportional to the actual building and were developed using Rhino 8. We use Blender (Version 3.7) to import models into Unity (2020.3.11f1) (as shown in Figure 3). The information presented in both the VR and AR systems and UI design is identical, and the construction of the scene is based on restoration research.

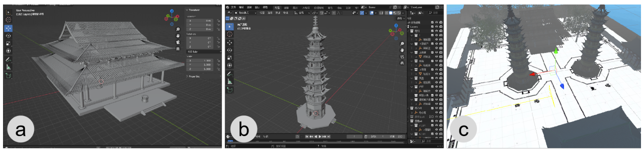


Figure 3: *The demonstration of (a) the 3D model of the main hall in Blender, (b) the 3D model of twin pagodas in Blender, and (c) the top view of the scene.*

4.1. Design of Virtual Reality *Shuangta*

The virtual reality system (as shown in Figure 1a-b) was designed to recreate the main hall of the cultural site by digitally reconstructing its architectural structure based on existing remains. To support close inspection of the exploded model of the Twin Pagodas, a dedicated viewing platform is provided within the scene. Participants can step onto the platform to gain a clearer view of the internal components of the reconstruction. The system supports the use of the Meta Quest 2 VR headset with two controllers. Users can **navigate** the virtual environment to simulate an on-site browsing experience and observe the reconstructed building from a realistic, immersive perspective. Both continuous and discrete locomotion techniques are allowed [ZLYL23] for users by pushing thumbsticks. Informational panels introducing specific relics are contextually placed throughout the environment and appear only when users approach designated locations. These panels can be interacted with using the VR controllers. Participants can **grab**, **drag**, and **position** them as needed. Interactive "expand" buttons embedded in the environment reveal exploded views of artifacts, enabling deeper exploration of their structure (as shown in Figure 4).

Figure 4: *Examples of VR system interactions.*

4.2. Design of Augmented Reality *Twin Pagodas*

In the augmented reality experience (see Figure 1c-d), participants used a mobile device to scan a designated image card, which triggered the display of 3D models of the Twin Pagodas and the reconstructed main hall within the application. Supplementary information, such as historical context and spatial layout, was presented through on-screen UI panels for a comprehensive understanding. The AR system was developed using Unity with the Vuforia plugin due to its robust image-based tracking and integration compatibility with Unity, and deployed on a Samsung Galaxy S10 mobile phone. Users could **tap** specific parts of the model to reveal small information panels or tap a blue square to access an exploded view. The model was fully rotatable, allowing users to explore it from multiple angles. Additional information was accessible by interacting with the on-screen panels, all of which could be hidden or displayed using a “toggle" button to allow for unobstructed model viewing (see Figure 5).

Figure 5: *Examples of AR system interactions.*

5. Methodology

5.1. Data Collection

To evaluate the research hypotheses, data were collected through structured questionnaires. One of the key instruments focused on active learning and was developed based on an extensive literature review conducted for this project. The specific items used in this questionnaire are listed in Table 2, and participants responded using a 5-point Likert scale, from 1 (Not at all familiar/willing) to 5 (Extremely familiar/willing). Items assessing system interactivity were adapted from studies by Guo et al. [GLS*], while those addressing content richness were derived from Wang’s [Wan] research. Additionally, the three dimensions related to the “Organism” component were measured using scales based on the work of Ben-Eliyahu et al. [BEMDS]. Notably, the active learning items in this study were informed by the theoretical framework proposed by Bonwell and Eison [BE91], ensuring alignment with established models in educational research.

5.2. Study Design

To evaluate two immersive cultural heritage experiences, we conducted an experimental study in a laboratory setting. Participants voluntarily signed up for the study through social media and were guided through the three experiment phases. The full procedure for

Table 2: *Measurement items used to validate the theoretical model.*

Variable	Item	Measured items	Factor loading VR	Factor loading AR
Interactivity	IN1	The content in this application was interactive.	0.837	0.789
	IN2	I had the feeling that I could influence the content of this application.	0.629	0.689
	IN3	When using this application, I am in control over the composition of the display.	0.769	0.820
	IN4	When using this application, I am in control over what I want to see.	0.645	0.671
Content Richness	CR1	This application meets my requirements for information content.	0.926	0.900
	CR2	This application provides high-quality information.	0.926	0.900
Affective Engagement	AE1	When using this application, I felt happy or excited.	0.607	0.615
	AE2	When using this application, I felt relaxed or calm.	0.307	0.323
	AE3	When using this application, I felt frustrated or annoyed.	0.906	0.917
	AE4	When using this application, I felt tired or sad.	0.877	0.920
	AE5	When using this application, I felt bored.	0.834	0.817
Behavioral Engagement	BE1	When using this application, I worked hard on the task.	0.768	0.846
	BE2	When using this application, I asked questions.	0.752	0.885
	BE3	When using this application, I checked to make sure I understood what I was doing.	0.797	0.918
	BE4	When using this application, I tried out my ideas to see what would happen.	0.818	0.206
Cognitive Engagement	CE1	I thought about how my ideas related to other things.	0.781	0.784
	CE2	When using this application, I was paying attention.	0.826	0.865
	CE3	When using this application, I figured out something about *Twin Pagodas*.	0.669	0.694
Active Learning	AL1	After using this application, I can recall and restate facts or knowledge about *Twin Pagodas*.	0.874	0.815
	AL2	After using this application, I can differentiate the different components of the contents I have learned and understand their relationships.	0.912	0.885
	AL3	After using this application, I can evaluate the value and effectiveness of the knowledge I have learned.	0.916	0.918

each participant took approximately 50 minutes. Ethics approval has been obtained from our institution's ethics committee prior to any data collection. Figure 6 demonstrates the study procedure.

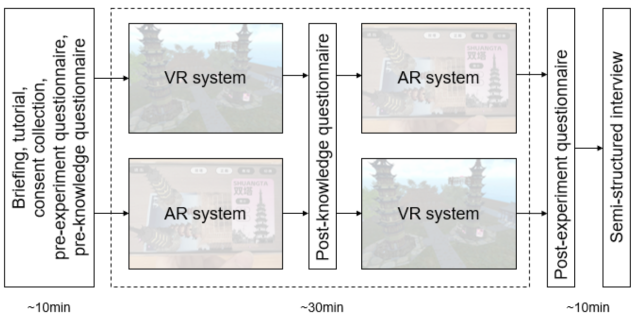


Figure 6: *The experiment procedure of the user study.*

(1) Pre-experiment Phase (10 mins): Participants were first briefed on the study's purpose and procedures. They then provided informed consent, completed a pre-experiment questionnaire, which was used to collect demographic information and assess prior knowledge of the *Twin Pagodas* (see Appendix A for details). To ensure consistent baseline familiarity, all participants received basic training on using both VR and AR systems.

(2) Experiment Phase (30 mins): The study employed a within-subjects design using a Latin square [Ric18] to counterbalance the order of system exposure. Each participant experienced both the VR and AR systems. Their primary task in each setting was to a) view the cultural heritage scenario and b) interact with its various features.

(3) Post-experiment Phase (10 mins): After completing each immersive experience, participants filled out a designed post-experiment questionnaire, which was used for validating the theoretical model (see Table 2). Additionally, users fill out the knowledge test questionnaire (see details in Appendix A) again only once after the first condition to avoid test fatigue and bias. A semi-structured interview will be conducted at the end, with two questions: (1) "Which system would you prefer to use for cultural heritage learning?" and (2) "Do you have any suggestions for two systems?".

6. Data Analysis and Results

6.1. Sample Characteristics

A total of 70 participants took part in this experiment (32 females and 38 males), with ages ranging between 21 and 26 years ($M = 22.33, SD = 2.517$). Most participants ($N = 53$) didn't visit *Twin Pagodas* before, with limited familiarity with the *Twin Pagodas* site ($M = 1.49, SD = 0.93$). While the participants were slightly familiar with VR ($M = 2.67, SD = 0.13$) and AR ($M = 2.71, SD = 0.13$) technologies, they showed a keen interest in exploring novel technological experiences ($M = 4.37, SD = 0.07$). Participants expressed a willingness for VR and AR technologies to enhance their travel experiences ($M = 4.37, SD = 0.618$) and were enthusiastic about learning about cultural heritage during their visits ($M = 3.69, SD = 0.894$).

6.2. Measurement Validity and Reliability

To ensure the robustness of the measurement model, we evaluated construct reliability, convergent validity, and discriminant validity. Internal consistency was assessed using Cronbach's alpha (CA) [Col] and composite reliability (CR) [BSY95], while convergent validity was examined through average variance extracted (AVE). These results are summarized in Table 3. Following the guidelines proposed by Fornell and Larcker [Lar81], most CA values exceeded the recommended threshold of 0.70, ranging from 0.628 to 0.884, showing good internal consistency. CR values ranged from 0.647 to 0.885, with most of them exceeding the criterion of 0.70, suggesting that construct reliability was overall high. The AVE values ranged from 0.515 to 0.857, all above the 0.50 threshold, supporting the model's convergent validity. These results demonstrate that the measurement model meets the established criteria for reliability and validity, providing a sound basis for further structural analysis.

Table 3: *Results of the construct reliability and validity test, showing the values of Cronbach's Alpha (CA), Composite Reliability (CR), and Average Variance Extracted (AVE).*

Factors	General Model			VR System			AR System		
	CA	CR	AVE	CA	CR	AVE	CA	CR	AVE
Interactivity	0.715	0.727	0.542	0.693	0.713	0.526	0.733	0.743	0.558
Content Richness	0.798	0.820	0.831	0.833	0.833	0.857	0.764	0.764	0.809
Affective Engagement	0.772	0.843	0.515	0.769	0.849	0.550	0.783	0.865	0.567
Behavioral Engagement	0.704	0.700	0.529	0.791	0.792	0.615	0.628	0.751	0.509
Cognitive Engagement	0.664	0.666	0.599	0.634	0.647	0.580	0.682	0.698	0.615
Active Learning	0.863	0.864	0.786	0.884	0.885	0.812	0.844	0.849	0.764

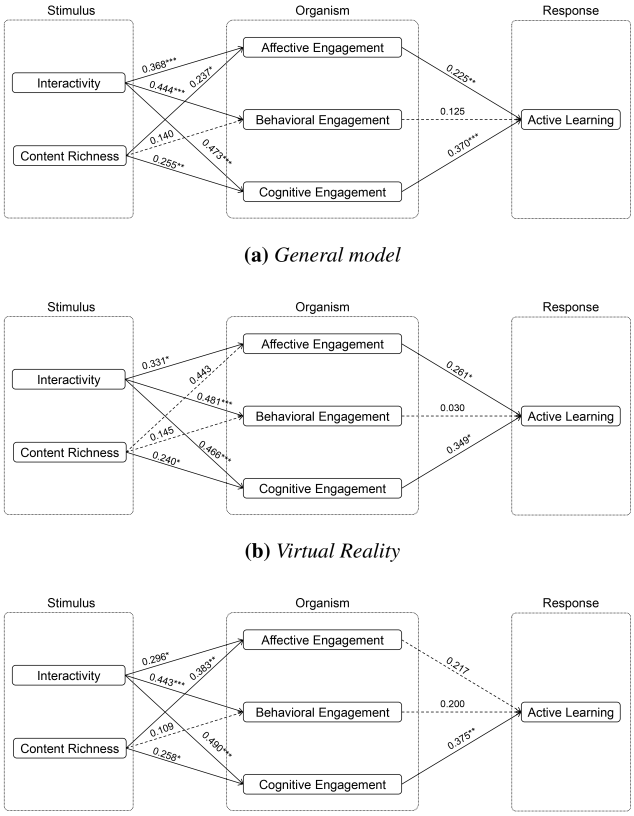
6.3. Structural Equation Modeling Analysis and Hypotheses Testing

Structural equation modeling (SEM) was conducted to test the research hypotheses, with results presented in Figure 7. We used Partial Least Squares (PLS), a widely adopted SEM technique suitable for analyzing exploratory models and developing measurement frameworks [HRS].

Hypotheses testing. The hypothesis testing results indicate distinct patterns across the three models. In the **general model**, interactivity significantly influences all engagement (H1: $\beta = 0.368, p = 0.000$; H2: $\beta = 0.444, p = 0.000$; H3: $\beta = 0.473, p = 0.000$). Content richness has a significant effect on affective ($\beta = 0.237, p = 0.018$) and cognitive engagement ($\beta = 0.255, p = 0.003$), but not on behavioral engagement ($\beta = 0.140, p = 0.090$). Both affective ($\beta = 0.225, p = 0.009$) and cognitive engagement ($\beta = 0.370, p = 0.000$) significantly predict active learning, whereas behavioral engagement ($\beta = 0.125, p = 0.147$) does not. As for the **VR model**, interactivity significantly affects affective ($\beta = 0.443, p = 0.005$), behavioral($\beta = 0.481, p = 0.000$) and cognitive engagement($\beta = 0.466, p = 0.000$), while content richness has a significant effect only on cognitive engagement($\beta = 0.240, p = 0.045$), showing no significant influence on affective ($\beta = 0.062, p = 0.668$) or behavioral engagement($\beta = 0.145, p = 0.257$). Affective ($\beta = 0.261, p = 0.043$) and cognitive engagement ($\beta = 0.349, p = 0.029$) are significant predictors of active learning, but behavioral engagement ($\beta = 0.030, p = 0.827$) remains non-significant. In the **AR model**, interactivity again significantly influences all three types of engagement (H1: $\beta = 0.443, p = 0.005$; H2: $\beta = 0.0481, p = 0.000$; H3: $\beta = 0.466, p = 0.000$). Content richness significantly affects affective ($\beta = 0.383, p = 0.005$) and cognitive engagement ($\beta = 0.258, p = 0.0.045$) but not behavioral engagement ($\beta = 0.109, p = 0.399$). In this model, only cognitive engagement ($\beta = 0.375, p = 0.008$) significantly predicts active learning, while the effects of affective ($\beta = 0.217, p = 0.080$) and behavioral engagement ($\beta = 0.200, p = 0.093$) are not statistically significant.

6.4. The Results of Learning Outcomes

This study compared participants' learning outcomes after engaging with two different immersive systems. Seventy participants were randomly assigned to two groups of equal size ($n = 35$). One group experienced the VR application first, followed by the knowledge questionnaire, while the other group experienced the AR application first. Analysis of the pre-test knowledge scores revealed a non-normal distribution ($p < 0.01$). We used a Mann-Whitney U test to compare the two groups. The test showed no significant difference between the VR and AR groups ($Z = -0.233, p = 0.984$), indicating that both groups had comparable baseline knowledge and could be treated as equivalent for analysis. We then conducted the Wilcoxon Signed-Rank Test to compare learning outcomes in each group. The results showed a significant difference between Pre-test and Post-test (VR: $Z = -5.111, p < 0.001$, AR: $Z = -5.176, p < 0.001$), meaning effective learning outcomes by using the two systems (see Figure 8). Post-test results met the assumption of normality and were analyzed using an independent t-test. There was no statistically significant difference in learning outcomes between the VR and AR conditions.



(a) *General model*

(b) *Virtual Reality*

(c) *Augmented Reality*

Figure 7: *Structural model and path coefficients of (a) General model, (b) Virtual Reality, and (c) Augmented Reality. Dotted lines indicate nonsignificant paths, while solid lines indicate significant paths. (*p<0.05; **p<0.01; ***p<0.001.)*

Table 4: *The results of discriminant validity analysis towards (a) general model, (b) VR system, and (c) AR system. Diagonal elements (bold) = sqrt(AVE), Off-diagonal = correlations. AE = Affective Engagement, AL = Active Learning, BE = Behavioral Engagement, CE = Cognitive Engagement, CR = Content Richness, IN = Interactivity.*

(a) *General Model*

	AE	AL	BE	CE	CR	IN
AE	**.717**					
AL	.449	**.887**				
BE	.386	.441	**.727**			
CE	.476	.554	.620	**.774**		
CR	.466	.597	.416	.549	**.911**	
IN	.515	.549	.531	.632	.621	**.736**

(b) *VR System*

	AE	AL	BE	CE	CR	IN
AE	**.716**					
AL	.466	**.901**				
BE	.493	.384	**.782**			
CE	.546	.511	.644	**.759**		
CR	.334	.441	.441	.527	**.925**	
IN	.481	.570	.570	.614	.616	**.724**

(c) *AR System*

	AE	AL	BE	CE	CR	IN
AE	**.724**					
AL	.434	**.874**				
BE	.295	.494	**.697**			
CE	.424	.590	.616	**.784**		
CR	.568	.657	.385	.565	**.898**	
IN	.536	.593	.511	.652	.625	**.747**

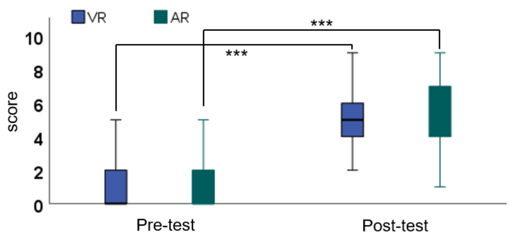


Figure 8: *The results of learning outcomes based on VR and AR systems, respectively.*

6.5. Quantitative Analysis

Participants' preferences for using different systems for learning. Based on our interview results, participants did not exhibit a clear preference for either system. However, a relatively larger number of participants ($N = 38$) showed a tendency toward VR, citing its higher level of interactivity and the seamless integration of information with cultural artifacts, which they felt facilitated more focused learning. One participant (P37) noted that "VR provided an immersive experience and offered multiple realistic perspectives for my observation". This resemblance to real-world environments was perceived as beneficial for learning, making the acquisition of knowledge less monotonous. Additionally, some participants ($N = 5$) pointed out that in the VR environment, the content introducing artifacts was contextually linked to their specific spatial locations, which made observation more convenient. The textual information on the VR panels was also reported to be larger, and the panel navigation was more easily controllable. For example, P65 noted that, "VR allows me to drag the panel in front of me so I can see more details.".

Participants' preferences for using different systems for visiting. Although the interview did not explicitly ask about participants' preferences for visiting heritage sites using immersive technologies, many raised this topic spontaneously. Their responses revealed contrasting views on the use of VR and AR in cultural heritage experiences. Overall, more participants expressed a preference for VR, citing its interactivity, intuitive interface, and rich content presentation. They noted that "the immersive nature of VR helped me better understand and retain information, particularly when exploring reconstructions of damaged or lost heritage sites" (P35). The heightened sense of presence was frequently mentioned as a key benefit. In contrast, participants who preferred AR valued its convenience and the efficiency with which it delivered information. Some found AR easier to engage with due to the physical fatigue or discomfort sometimes caused by extended VR use ($N = 10$). Others appreciated AR's compatibility with smartphones, for instance, P57 mentioned that "AR allowed me to interact with digital content while remaining aware of my real-world surroundings". P70 participants proposed a combined approach-using VR in indoor settings such as museums for deeper immersion, and AR in outdoor environments as a supplementary guide during on-site visits.

7. Discussion

7.1. Influence of Interactivity on Active Learning through VR and AR systems

Cognitive engagement is a significant source for active learning towards VR and AR systems, and interactivity is found to be a salient antecedent for this construct. This finding is in line with previous studies [Kum, Gao], which confirmed that interactivity in applications significantly influences user engagement. In the VR condition, interactivity has a significant positive impact on both affective engagement and cognitive engagement, which in turn significantly enhances active learning. This finding is identical to previous research [PPM]. Most participants reported that the immersive environment and engaging interactions offered by VR fostered stronger affective resonance and cognitive stimulation, motivating them to participate more actively in the learning process. They also indicated that being able to freely and closely examine cultural heritage models within a highly realistic virtual environment deepened their understanding and appreciation of artifact details.

In contrast, although interactivity in the AR condition also significantly influenced affective and cognitive engagement, the overall path coefficients were slightly weaker than those observed in VR. Furthermore, affective and behavioral engagement did not significantly predict active learning. This is contrary to previous study [YD13]. Participants noted that their learning experience with AR systems was comparable to that of traditional paper-based materials. The relatively limited interactivity of AR led to feelings of boredom and reduced motivation during the learning process.

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7.2. Influence of Content Richness on Active Learning through VR and AR systems

Content richness plays a vital role in enhancing users' cognitive engagement [LCM*]. Our findings indicate that content richness in the VR system significantly boosts cognitive engagement, which in turn positively influences active learning. Though participants mentioned that abundant visual and spatial information offered an immersive and meaningful learning experience, content richness did not show a significant effect on affective or behavioral engagement. Some users indicated that during their VR experiences, they were more focused on the interactivity of the system and preferred to explore the entire scene rather than superficially browse informational panels. This suggests that immersion and interactivity in VR may be more critical than the quantity of content alone. This is consistent with Makransky's study [MTM19], which found that excessive information density in VR can cause cognitive overload and distraction, thereby reducing learning effectiveness.

Similarly, for AR conditions, content richness has a significant influence on affective engagement. Several participants mentioned that AR's integration of textual information made it easier to access desired content, thereby enhancing their emotional connection to the experience. Its impact on behavioral engagement was minimal. Some users explained that although AR improved the efficiency of information retrieval, it did not necessarily encourage broader interaction with the environment, indicating that convenience alone may not be sufficient to foster deeper behavioral involvement.

However, behavioral engagement in both conditions did not show a significant effect on active learning. This suggests that observable behaviors or interactions may not reliably reflect a learner's internal cognitive state. This aligns with Posner et al.'s findings [Pos], which noted that eye gaze alone is not a definitive indicator of attention, as individuals may appear focused while mentally disengaged.

7.3. Practical Implications

This study provides insights for designing immersive learning experiences in cultural heritage contexts. For VR environments, designers should **prioritize enhancing interactivity** to deepen cognitive engagement and foster meaningful learning. Features such as explorable 3D reconstructions, intuitive navigation, and contextualized content delivery can significantly improve user outcomes. For AR applications, developers should focus on **optimizing content richness and accessibility**. Use clear and concise information overlays, seamless integration with the physical environment, and mobile-friendly interfaces to increase affective engagement. Additionally, the findings suggest that immersive tools could be tailored to specific settings: VR is preferred for indoor, museum-like environments, while AR is more expected for outdoor or on-site explorations. Combining both approaches could support hybrid learning experiences that balance immersion with real-world context. Educators and curators can use these insights to design more effective educational strategies, ensuring immersive technology serves both engagement and learning goals.

7.4. Limitations and Future Work

As with any study, this research has several limitations. The participant pool consisted primarily of university students ($N = 70$) aged between 19 and 26, limiting the generalizability of the findings to broader audiences. In terms of system design, user feedback indicated that the interactivity and entertainment value of both the VR and AR experiences could be improved. Additionally, the textual content was often dense and included specialized architectural terms that were not clearly explained, reducing accessibility for non-experts. The experiences were also limited to visual interaction, lacking multimodal feedback such as sound or haptics.

Future research could address these limitations by recruiting a more diverse participant group and increasing the sample size. From a design perspective, interactivity could be significantly enhanced. Suggestions include recreating realistic ancient scenes in VR, incorporating interactive characters to guide learning, and enabling more precise manipulation of architectural elements in AR, such as zooming into specific components. Users also requested clearer navigation aids, such as a virtual tour guide in VR or highlighted prompts in AR to indicate clickable features. For AR specifically, the card-based scanning method, combined with the small phone display, limited the size and clarity of the models. Future designs could use ground plane detection to render full-scale architectural models, enhancing spatial understanding. Some users also suggested integrating AR directly into the real heritage site, allowing them to scan the ruins of the main hall and view the restored Twin Pagodas in context.

8. Conclusion

This study investigated the impact of interactivity and content richness on users' engagement and active learning in cultural heritage experiences delivered through VR and AR technologies. Grounded in the Stimulus-Organism-Response (SOR) framework and engagement theory, the research demonstrated that immersive systems can effectively foster affective, behavioral, and cognitive engagement, each of which significantly contributes to active learning outcomes. By designing two immersive experiences featuring the *Twin Pagodas*, the study compared how different technological affordances shape user engagement. The results showed that interactivity strongly influenced all three engagement dimensions in both VR and AR settings, while content richness had a more pronounced effect on affective and cognitive engagement. These findings note the need for thoughtful integration of design features that support both interaction and content depth. The experiment also revealed that while both VR and AR improved users' learning outcomes. This research contributes to the growing field of digital heritage by offering a validated model for understanding how immersive technologies support active learning. It also provides practical guidance for designers and educators aiming to enhance user engagement and educational value through interactive heritage applications.

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Appendix A: The demographic in Pre-experiment Questionnaire

No.	Content
1	Participant Number
2	Gender: ◯ Female ◯ Male ◯ Others
3	Age
4	Career: ◯ Student ◯ Office Staff ◯ Professional ◯ Business people ◯ Others
5	Please evaluate your knowledge of Virtual Reality (VR) applications (e.g., Beat Saber, VRChat, SteamVR): ◯ Not at all familiar ◯ Slightly familiar ◯ Somewhat familiar ◯ Moderately familiar ◯ Extremely familiar
6	Please evaluate your experience of Augmented Reality (AR) applications (e.g., Alipay scan cards, Pokémon GO, AR digital artifacts): ◯ Not at all familiar ◯ Slightly familiar ◯ Somewhat familiar ◯ Moderately familiar ◯ Extremely familiar
7	How willing are you to experience new technologies? ◯ Not at all willing ◯ Slightly willing ◯ Neutral ◯ Willing ◯ Very willing
8	Have you ever been to Twin Pagodas? ◯ Yes ◯ No
9	Please evaluate your familiarity with the Twin Pagodas: ◯ Not at all familiar ◯ Slightly familiar ◯ Somewhat familiar ◯ Moderately familiar ◯ Extremely familiar
10	Please evaluate your frequency of visiting cultural heritage (e.g., museums, historic sites): ◯ Never ◯ Once a year or less ◯ Once a half year ◯ A couple of times a year ◯ Once a month or more
11	How willing are you to learn related knowledge while visiting cultural heritage? ◯ Not at all willing ◯ Slightly willing ◯ Neutral ◯ Willing ◯ Very willing
12	Compared with traditional visits, how willing are you to choose VR/AR to enhance your tourism experience? ◯ Not at all willing ◯ Slightly willing ◯ Neutral ◯ Willing ◯ Very willing

Appendix B: The Knowledge Questionnaire

No.	Content
1	The Shuangta is also called?
2	According to the restoration inference, the roof of the main hall is?
3	The surviving site of the Shuangta has stone pillars in the shape of?
4	When was the main hall of the Shuangta built?
5	What type of towers are the Shuangta?
6	According to the restoration inference, the mortise and tenon structure used for the capital and architrave of the main hall is?
7	What is the form of the outer walls of the Shuangta?
8	The shape of the Shuangta emulates what type of tower?
9	Shuangta tower wall each floor in addition to the four sides of the pot door, the other four sides of the hidden out of the window type for?
10	The masonry at the base of the Shuangta is?