XR Exhibit+: An AI-Enhanced XR Museum Guide based on Constructivism and Connectivism Theories

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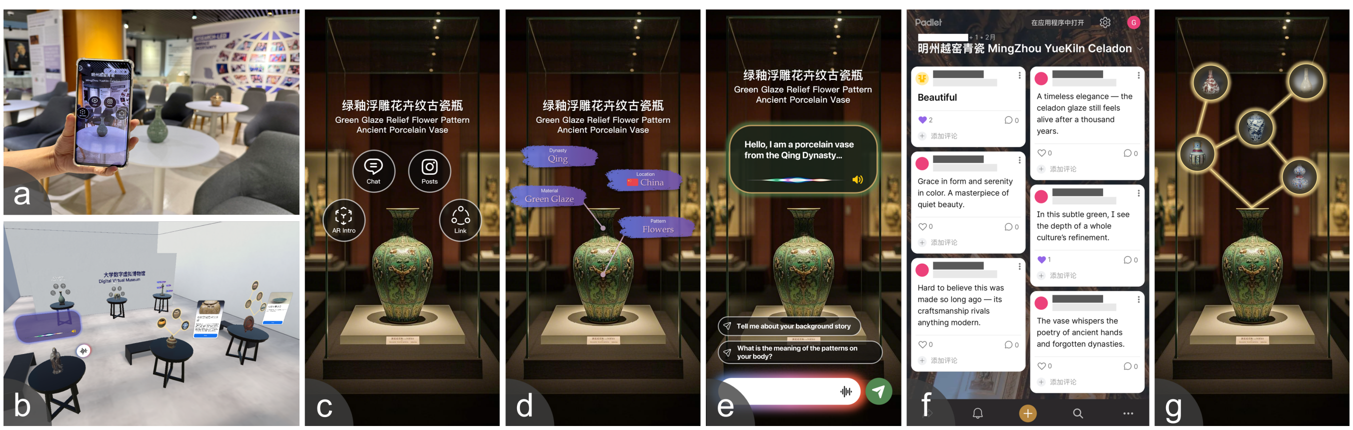

Figure 1: Visitors using *XR Exhibit+* in (a) a physical museum and (b) a virtual museum. Screenshots showing (c) the main interfaces of *XR Exhibit+* with four key features: (d) tooltip introduction for the exhibit, (e) an LLM-based chatbot with real-time voice recognition and synthesis, (f) a message board showing visitors' individual interpretations, and (g) a knowledge graph showing other related exhibits.

Abstract

In response to the growing demand for engaging, personalized, and pedagogically grounded museum experiences, we present *XR Exhibit+*, an intelligent XR museum guide that integrates Extended Reality (XR) and Large Language Models (LLMs), grounded in constructivism and connectivism learning theories. *XR Exhibit+* features four core components: annotated tooltips, an LLM-powered conversational interface, a visitor message board, and a semantic exhibit graph, fostering contextual learning, active meaning-making, and knowledge networking. We developed both Augmented Reality (AR) and Virtual Reality (VR) museum guides and conducted a mixed-method study ($N = 28$) to evaluate their effectiveness.

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Results show that *XR Exhibit+* significantly improves engagement, learning, and emotional connection in both physical and virtual museum settings compared to traditional approaches. No significant differences were found between AR and VR implementations, indicating strong cross-context usability. Qualitative feedback emphasized the natural interaction with exhibits and the value of shared visitor reflections. Our study demonstrates the potential of theory-driven AI-enhanced XR systems to enrich museum learning and lays the groundwork for future adaptive, immersive educational tools.

CCS Concepts

• **Human-centered computing → Mixed / augmented reality**; **Virtual reality**; **User studies**.

Keywords

Museum Experience; Large Language Model; Extended Reality

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1 Introduction

In an era where museums are increasingly recognized not just as repositories of artifacts but as dynamic learning environments, there is a growing need to rethink how visitors engage, interpret, and internalize cultural knowledge. With the rapid advancement of Large Language Models (LLMs) and Extended Reality (XR) technologies, museums are presented with unprecedented opportunities to transform static displays into interactive, adaptive, and engaging experiences [4, 11, 22, 24]. However, the deployment of these technologies frequently lacks a unified pedagogical framework, resulting in disjointed and ineffective implementations. This gap between what visitors expect and how content is delivered underscores the importance of adopting systems grounded in contemporary learning theories.

Constructivism and connectivism are two influential learning theories that have shaped modern educational practices, particularly in the context of the digital age [12, 15]. Based on constructivism and connectivism theories, we designed and implemented an AI-enhanced XR museum guide, (*XR Exhibit+*), which reimagines museum engagement in both physical and virtual settings. *XR Exhibit+* is built upon the idea that learning occurs most effectively when visitors can engage with content in a personalized, contextual, and socially meaningful way. To support this, the system integrates XR technologies with LLMs, enabling multimodal interaction with cultural artifacts. Guided by constructivism principles, *XR Exhibit+* emphasizes immersive exploration, real-time feedback, and self-directed learning. In parallel, it aligns with connectivism thinking by linking exhibits across institutions, incorporating AI agents, and fostering community-driven interpretation and dialogue. Specifically, our study aims to answer the following question:

RQ1 Compared to a traditional museum visit, can *AR Exhibit+* enhance physical museum experiences?
RQ2 Compared to a VR museum visit that replicates the physical museum settings, can *VR Exhibit+* enhance virtual museum experiences?
RQ3 Do users' museum experiences differ when using *AR Exhibit+* and *VR Exhibit+*?

Our study made the following contributions: (1) We present an intelligent XR guide system (i.e. *XR Exhibit+*) based on the constructivism and connectivism learning theories, aiming to enhance the museum experience, especially the learning experience. (2) We show that *XR Exhibit+* can significantly enhance the *engagement*, *knowledge and learning* and *emotional connection* in both physical museums (AR-based) and virtual museums (VR-based). In addition, the *VR Exhibit+* significantly improved the sense of *meaningful experience*. No significant experience difference was found between *AR Exhibit+* and *VR Exhibit+*.

2 Related Work

2.1 Large Language Model and Extended Reality in Museums

LLMs enable natural, unscripted communication, enhancing the realism and engagement of the museum experience [4, 8, 19]. These models can provide detailed, on-demand information about exhibits, enriching the education of museum visits [5, 6, 24]. For example, an LLM-based virtual art guide can answer questions about artwork details, creator information, and historical context [5]. Integrating LLMs with XR can create dynamic and immersive learning environments, fostering a deeper appreciation of cultural heritage and these technologies help document and preserve cultural heritage, crucial for education amid environmental changes [8].

XR is an umbrella term of reality-based technologies, such as Virtual Reality (VR) and Augmented Reality (AR). XR technologies allow visitors to experience exhibitions in novel ways, such as traveling back in time or viewing the original appearances of exhibits [3, 14, 18]. Examples include the *Battle on Neretva VR* in the Museum in Jablanica, which provides an immersive historical experience [18]. Although AR does not support fully immersive displays as VR does, it facilitates interactive storytelling, enhancing the perception and understanding of cultural heritage [10, 13, 14]. Museums have been actively adopting XR to create multisensory experiences, blending physical and digital worlds to engage visitors cognitively and emotionally [17].

However, these technologies are often deployed without a cohesive pedagogical foundation, leading to fragmented and underwhelming implementations. This disconnection between visitor expectations and delivery methods highlights the need for systems rooted in modern learning theories.

2.2 Constructivism and Connectivism Theories

Constructivism learning theory emphasizes that knowledge is actively constructed by learners through experience, reflection, and social interaction [1, 12]. Learners engage with real-world problems and collaborate with others, making learning contextual and meaningful. In contrast, connectivism, developed in response to

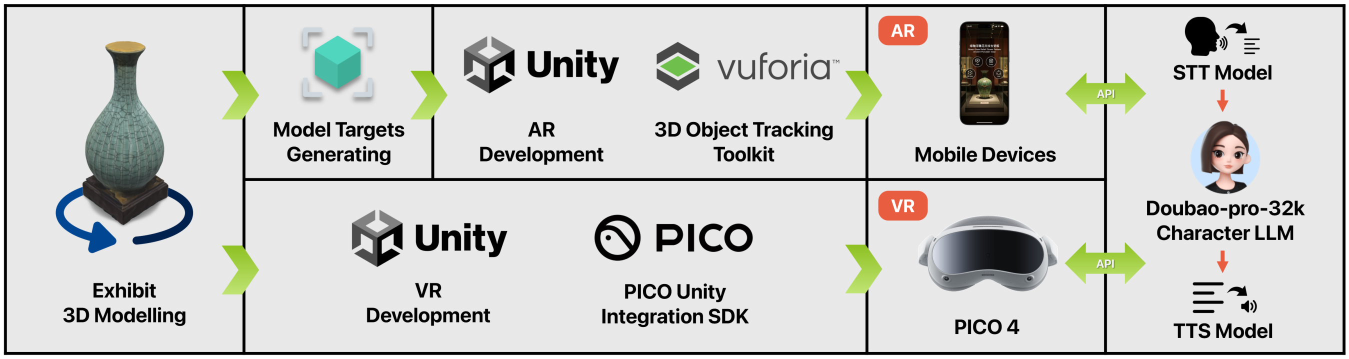


Figure 2: Technical implementation of *XR Exhibit+*. STT=Speech-to-Text, LLM=Large Language Model, TTS=Text-to-Speech.

technology's impact on learning, sees knowledge as distributed across networks and learning as navigating and utilizing these connections [7, 12]. It highlights the role of digital tools, social media, and information networks in shaping how individuals acquire and update knowledge [7, 21].

Both theories stress the need for immersive, relevant, and socially connected learning environments. Constructivism emphasizes learner agency, context, and collaboration, while connectivism extends these principles through technology and constant connectivity. Integrating both encourages educational experiences that engage learners cognitively and socially, preparing them for an information-rich world.

Grounded in these theories, *XR Exhibit+* redefines visitor engagement both physically and virtually. Using XR and LLM technologies, it fosters personalized, contextual, and socially meaningful interactions. Inspired by constructivism, it offers immersive exploration, real-time feedback, and self-directed learning. In line with connectivism, it links exhibits across institutions, uses AI agents, and promotes collaborative interpretation and dialogue.

3 System Design and Implementation

3.1 Formative Study

We conducted semi-structured interviews with five visitors (2 male, 3 female) aged between 21 and 28 (M = 25, SD = 2.28) and one museum administrator, aiming to identify pain points in the current museum visiting experience. Four interviewees noted that traditional methods of presenting exhibit information, such as text, images, and videos, impose a **high information load** on visitors, and the fixed nature of these materials often **fails to cater to visitors' diverse interests**. The interviewees mentioned difficulties in **emotionally connecting** with exhibits (N = 2) and expressed a desire to **share their insights** about the exhibits with other visitors (N = 2). Furthermore, two respondents pointed out that related exhibits from the same cultural background are often located in different museums, making it **difficult to gain a comprehensive understanding** of the culture background.

3.2 Design of *XR Exhibit+*

Informed by the interview results and guided by the constructivism and connectivism learning theories, we designed four core features for *XR Exhibit+*: ***Tooltip introduction***, ***LLM chatbot***, ***Message board***, and ***Exhibit network***, as showed in Figure. 1.

Tooltip introduction. Based on the recent study investigating textual layout in museums [20], we implemented annotated exhibit descriptions as it reduces information load, supporting constructivist principles of contextual, visual, and embodied learning.

LLM chatbot. The chatting function allows real-time, personalized conversations with exhibits [24]. This feature is powered by a large language model, simulating self-aware agents, it promotes active knowledge construction and network-based interaction, bridging the two theories.

Message board. User-generated content encourages visitors to contribute personal reflections and interpretations [9]. This feature is achieved via a shared message board (based on Padlet[1]), reinforcing social constructivist learning and fostering community knowledge.

Exhibit network. Connectivist learning theory emphasizes building a complete knowledge system by linking distributed knowledge nodes into an interconnected network [7, 23]. This feature visualizes semantic connections between related exhibits across institutions, embodying the connectivism notion of forming meaningful relationships across distributed knowledge nodes.

In physical museums, visitors can use *AR Exhibit+* to access AR panels by capturing them with their smartphones' cameras; in virtual museums, the *VR Exhibit+* allows users to navigate the virtual museum environment and interact with exhibits using VR controllers.

3.3 Implementation of *XR Exhibit+*

Figure 2 illustrates the technical implementation of *XR Exhibit+*. First, we used an iPhone 16 Pro equipped with LiDAR to perform 3D scanning and modeling of 6 exhibits from a university museum, using Apple Object Capture API[2]. The *AR Exhibit+* was developed using Vuforia[3]. We imported the scanned artifact models into the Vuforia Model Target Generator to create model tracking targets, which were then imported into Unity (version 2022.3.61f1) for AR development. Since Vuforia's model tracking does not rely on LiDAR, *AR Exhibit+* is compatible with most Android and iOS devices.

[1] https://padlet.com/
[2] https://developer.apple.com/documentation/realitykit/realitykit-object-capture/
[3] https://developer.vuforia.com/

For the *VR Exhibit+*, we first built a virtual museum in Unity that resembles the layout of the university museum. The scanned artifact models were placed inside this virtual environment. The application was developed using the PICO Unity Integration SDK[4] and deployed to a PICO 4 headset.

For the ***LLM chatbot*** feature, the recorded audio of visitor's input is first transmitted via an API to Tencent Cloud[5] Speech-to-Text (STT) model for transcription. The resulting text, along with contextual information about the current exhibit, is then passed to Doubao-pro-32k[6], a large language model developed by ByteDance and optimized for role-playing tasks, to generate an appropriate exhibit response. This generated response is subsequently delivered to Tencent Cloud's Text-to-Speech (TTS) model, which synthesizes the reply using natural-sounding speech in a variety of voice profiles, thereby enabling a realistic and immersive conversational experience with the exhibit.

4 Evaluation

4.1 Measures

The Museum Experience Scale (MES) [16] was used to assess participants' museum experiences. It encompasses four key dimensions that influence the museum experience: Engagement, Knowledge / Learning, Meaningful Experience, and Emotional Connection. The Museum Multimedia Scale (MMGS) [16] was employed to evaluate the usability, ease of learning and control, and the quality of interaction of the multimedia guide systems in museums. We also adopted the System Usability Scale (SUS) [2] to evaluate the system usability of both the *AR* and *VR Exhibit+*. Participants responded to the items using a 5-point Likert scale, where 1 indicated "strongly disagree" and 5 indicated "strongly agree." Participants were also invited to rate the four functions of *XR Exhibit+* based on their preferences.

4.2 Procedure

Participants were randomly and evenly divided into two groups: (1) *AR Exhibit+* and (2) *VR Exhibit+*. The experiment was approved by the university's ethics committee. Specifically, the experiment has three phases:

1. ***Pre-experiment Phase (~8 min).*** Participants were introduced to the purpose and procedure of the experiment, read and signed the informed consent form, completed a demographic questionnaire, and learned how to use the *XR Exhibit+*.

2. ***Experiment Phase (~20 min).*** This phase include two experimental conditions, the sequence of which was counterbalanced by a Latin Square Design. One group first engaged in a **(1) Traditional museum visit**: they freely explored either the physical artifacts at the university museum or the virtual artifacts in a virtual museum using a VR headset. The task was to read the textual descriptions displayed next to each exhibit. After completing this visit, they completed a post-experiment questionnaire. They then proceeded to **(2) *XR Exhibit+* visit**: exploring physical artifacts using *AR Exhibit+* on a smartphone or virtual artifacts with *VR Exhibit+*. The task was to interact with the four functions of the system: viewing tooltip descriptions, chatting with the exhibits, browsing and posting on the message board, and exploring related artifacts. Upon completion of this session, they completed another post-experiment questionnaire and rated the four functions of *XR Exhibit+* based on their satisfaction on scale of 1 to 10 (10 = Extremely Satisfied). The other group followed the reverse order to counterbalance any potential order effects, ensuring the validity and accuracy of the experimental results.

3. ***Post-experiment Phase (~5 min).*** Participants were invited to take part in a brief semi-structured audio-recorded interview to provide additional feedback and suggestions regarding *XR Exhibit+*.

4.3 Participants

We recruited a total of 28 participants (13 male, 15 female) for the experiment, aged between 19 and 26 ($M = 21$, $SD = 1.87$), all of whom were university students. More than half of the participants ($N = 15$) visit museums 1–2 times per year. Participants self-assessed their familiarity with relevant technologies using a 5-point Likert scale, ranging from 1 (not familiar at all) to 5 (very familiar), showing a relatively high familiarity with XR ($M = 3.07$, $SD = 1.00$) and LLM ($M = 3.62$, $SD = 0.96$).

5 Analysis and Results

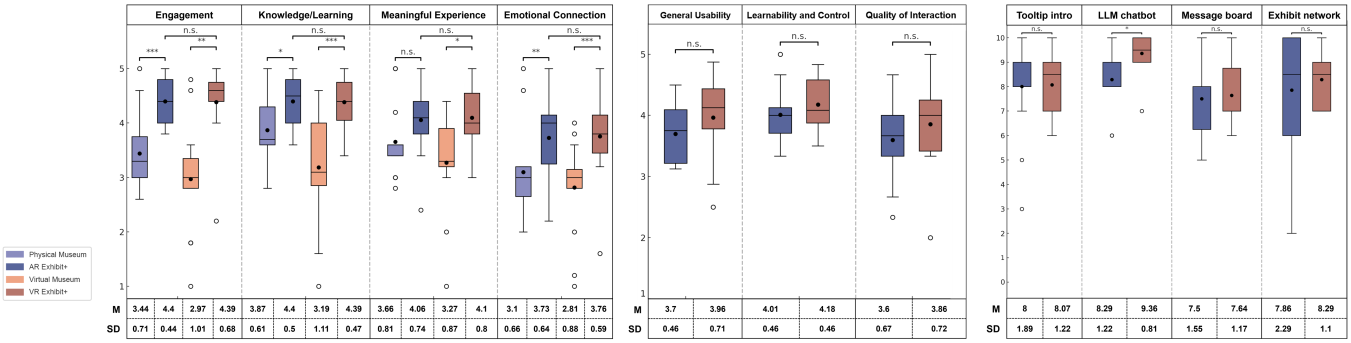
The statistical analysis was performed using IBM SPSS Statistics (version 30). Figure 3 shows the results.

5.1 Quantitative Analysis

5.1.1 Physical Museum v.s. AR Exhibit+. Significant differences were found between the *Physical Museum* and the *AR Exhibit+* in *Engagement* ($t(13) = -4.889, p < .001$), *Knowledge/Learning* ($t(13) = -2.844, p = .007$), and *Emotional Connection* ($Z = -4.889, p = .004$). Participants were significantly more engaged when using *AR Exhibit+* ($M = 4.4, SD = 0.44$) than *Physical Museum* visits ($M = 3.44, SD = 0.71$). They also reported greater *knowledge and learning* when using *AR Exhibit+* ($M = 4.4, SD = 0.5$) than that of *Physical Museum* visits ($M = 3.87, SD = 0.61$). Significantly greater *emotion connection* was perceived when using *AR Exhibit+* ($M = 3.73, SD = 0.64$), compared to the *Physical Museum* visits ($M = 3.1, SD = 0.66$). However, no significant difference was shown between the two conditions in *meaningful experience*, $Z = -2.212, p = .027$.

5.1.2 Virtual Museum v.s. VR Exhibit+. Similarly, significant differences were found between *Virtual Museum* and *VR Exhibit+* in *Engagement* ($Z = -3.149, p = .002$), *Knowledge/Learning* ($t(13) = -4.926, p < .001$), *Meaningful Experience* ($Z = -2.737, p = .006$), and *Emotional Connection* ($Z = -3.306, p < .001$). Participants were significantly more engaged when using *VR Exhibit+* ($M = 4.39, SD = 0.68$) than *Virtual Museum* visits ($M = 2.97, SD = 1.01$). They also reported greater *knowledge and learning* when using *VR Exhibit+* ($M = 4.39, SD = 0.47$) than that of *Virtual Museum* visits ($M = 3.19, SD = 1.11$). In comparison to *Virtual Museum* visits ($M = 3.27, SD = 0.87$), *VR Exhibit+* ($M = 4.1, SD = 0.8$) also significantly enhanced their *meaningful experiences*. Significantly greater *emotion connection* was perceived when using *VR Exhibit+*

[4]https://developer-cn.picoxr.com/resources/
[5]https://cloud.tencent.com/
[6]https://console.volcengine.com/ark/region:ark+cn-beijing/model/detail?Id=doubao-pro-32k



(a) Museum Experience (b) Multimedia Guide (c) Feature Satisfactions

Figure 3: Box-plots and tables of descriptive statistics (means and standard deviations) showing the results of the (a) museum experience, (b) multimedia guide and (c) user satisfaction with the four features of *XR Exhibit+*. Significance p-value: *: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$. n.s.: not significant.

($M = 3.76, SD = 0.59$), compared to the *Virtual Museum* visits ($M = 2.81, SD = 0.88$).

5.1.3 *AR Exhibit+ v.s. VR Exhibit+.*

The *XR Exhibits+* systems have usability scores exceeding the threshold score of 68: 72.9 ($SD = 11.2$) for the *AR Exhibit+* and 78.75 ($SD = 15.9$) for the *VR Exhibit+*. No significant differences were found between *AR Exhibit+* and *VR Exhibit+* in museum experience (*Engagement*: $Z = -.489, p = .625$; *Knowledge/Learning*: $t(26) = -.078, p = .938$; *Meaningful Experience*: $t(26) = .184, p = .855$; *Emotional Connection*: $t(26) = .098, p = .923$) or multimedia guide experience (*General Usability*: $t(26) = -1.180, p = .249$; *Learnability and Control*: $t(26) = -.964, p = .344$; *Quality of Interaction with the Guide*: $t(26) = -.994, p = .330$).

We also analyzed participants' satisfaction with the system functions between *AR Exhibit+* and *VR Exhibit+*. Mann-Whitney U tests showed no significant difference in the ***Tooltip introduction*** ($Z = -.283, p = .777$), ***Message board*** ($Z = -.118, p = .906$), or ***Exhibit network*** features ($Z = -.094, p = .925$) between AR and VR. However, users were significantly more satisfied with the ***LLM chatbot*** in *VR Exhibit+* ($M = 9.36, SD = 0.81$) than *AR Exhibit+* ($M = 8.29, SD = 1.22$), $Z = -2.472, p = .013$.

Additionally, we compared user satisfaction with the four core features in AR and VR, respectively. A Friedman test showed no significant difference across them in *AR Exhibit+*, $\chi^2(3) = 2.482, p = .479$. However, a significant difference was found among the four features in *VR Exhibit+*, $\chi^2(3) = 16.282, p < .001$. Post-hoc analysis showed that users were significantly more satisfied with the ***LLM chatbot*** ($M = 9.36, SD = 0.81$) than the ***Message board*** ($M = 7.64, SD = 1.17$) when using *VR Exhibit+*.

5.2 Qualitative Analysis

Participants generally believed that *XR Exhibit+* significantly enhanced the museum experience ($N = 24$), particularly in terms of learning. As P8 noted: "*Compared to plain textual descriptions, the tooltip and chat functions reduced the information load. These made the visit more engaging.*" Similarly, P12 remarked: "*The chat feature allows me to explore aspects that I'm interested in. I like this kind of personalized tour experience.*" Many Participants ($N = 18$) gave high praise to the voice chat experience. P16 commented: "*I really liked the voice of the exhibits—it matched their appearance and historical background very well.*" P18 added: "*The conversation with the exhibits felt very natural, like talking face-to-face with a person. Their responses were also satisfying.*" Half participants ($N = 14$) found the message board feature both interesting and enriching, as it allowed them to interact with other visitors and gain diverse perspectives on the exhibits.

However, participants also pointed out several areas for improvement. Some participants ($N = 7$) reported that they received overly brief or unsatisfactory answers when asking in-depth questions that were not covered in the training data of the system. Additionally, some participants ($N = 9$) expressed uncertainty about what to ask the exhibits. As P22 mentioned: "*I felt a bit lost when using the chat feature because I didn't know what questions to ask.*" Another commonly raised issue was the slow speed of speech synthesis ($N = 6$). P15 noted: "*The wait time for the exhibit's response was a bit long. This affected the conversation experience.*"

6 Discussion

6.1 *AR Exhibit+* for Physical Museum Visits

Addressing **RQ1**, the study found that deploying *AR Exhibit+* in a physical museum significantly heightened visitor *engagement*, *knowledge and learning*, and *emotional connection* relative to a traditional visit, though it did not significantly increase *meaningful experience*. This suggests that layering digital information in real exhibition settings effectively reduces visitors' cognitive load and supports real-time, interactive knowledge construction—consistent with constructivist principles of "contextualized, self-paced learning" [1]. Visitors can call up prompts or initiate dialogues with exhibits on demand, focusing on content they find most relevant, thus triggering deeper processing and self-explanation.

AR Exhibit+ did not significantly enhance the dimension of *meaningful experience*. Questions evaluating this dimension prompted users to reflect the significance of the exhibits, the efforts put into thinking about the exhibition, the sense of wonder when seeing rare and important exhibits, and the continued interest after the visits. We observed that visitors sometimes felt uncertain about what questions to ask during the interaction, which limited their ability to reflect deeply on the significance and meaning of the exhibits. Additionally, while the system aimed to reduce information overload, some responses were overly brief thus failed to stimulate in-depth thinking, leading to a lack of cognitive engagement. The limited number of exhibits and relatively modest visual impact of AR on a smartphone screen also reduced the sense of wonder, typically evoked by rare artifacts.

6.2 *VR Exhibit+* for Virtual Museum Visits

For **RQ2**, *VR Exhibit+* surpassed a traditional VR museum in all museum experience dimensions. The highly immersive VR environment, combined with LLM-powered conversational exhibits, enabled on-demand, responsive interactions. This not only enhanced presence but also addressed common issues in traditional VR settings such as information silos and cognitive disconnection. Additionally, voice interactions and visualized knowledge graphs enabled visitors to connect concepts across exhibits and timelines, reflecting connectivism learning principles of "nodes–networks–flows of meaning" [7]. This facilitated conceptual transfer and long-term memory formation. It should be noted that this study focused on a single museum visit. The long-term effects of *VR Exhibit+*, including whether it sustains novelty and avoids interaction fatigue, require further longitudinal studies. Moreover, a few participants noted the issue of delays in voice synthesis, suggesting that further technical refinement and better-designed prompts are needed.

6.3 Comparing AR and VR for Museum Experiences

Concerning **RQ3**, statistical tests revealed no significant differences between *AR Exhibit+* and *VR Exhibit+* in either the overall museum experience or multimedia guide experience. This indicates that the core design principles rooted in constructivism and connectivism are transferable across platforms, providing curators with a flexible framework for technology deployment. The experience equivalence between AR and VR suggests that museums can mix and match based on target audiences, venue constraints, and budget. Hybrid exhibition formats may help broaden accessibility across different contexts. Furthermore, no significant gender or tech-familiarity effects were found, indicating strong usability for novice users.

The comparison between AR and VR modalities, and among the four features implemented in the system also showed some interesting findings. For example, user satisfaction with ***LLM chatbot*** was rated significantly higher in *VR Exhibit+* than that in *AR Exhibit+*. In the VR environment, users are fully immersed in a virtual space, which mitigated the distractions in the real world, thus contributing to users' attention and engagement. Unlike in AR, where users interact through mobile screens layered over real-world distractions, the VR interface presents the chatting feature as a seamlessly integrated part of the environment. This stronger presence and contextual integration of the chat interface in VR makes it more salient, accessible, and satisfying for users.

In addition, users reported significantly higher satisfaction with the ***LLM chatbot*** in *VR Exhibit+* compared to the ***Message board***. A likely reason is that the ***Message Board*** relied on a 2D web interface within the VR environment, potentially disrupting immersion. This highlights a need to improve messaging functions in VR by avoiding 2D elements. Although the ***Message board*** supports both typing and voice input, some participants preferred typing due to familiar web-based habits. However, using a virtual keyboard with VR controllers is more cumbersome than a physical keyboard, likely reducing satisfaction with this feature.

6.4 Limitations and Future Work

While this study presents promising evidence for the effectiveness of AI-enhanced XR experiences in both physical and virtual museum settings, several limitations must be noted. First, the sample size was small ($N = 28$) and mainly composed of university students, limiting generalizability to broader demographics such as older adults, children, and culturally or educationally diverse users. Second, the exhibits were limited to a single university museum and specific artifacts (e.g., alumni donations, souvenirs), which may not reflect other domains like science, history, or ethnography museums. Third, the study focused on short-term experiences without assessing long-term knowledge retention, behavioral intentions (e.g., future visits), or learning transfer. Although LLM-based conversational agents were well-received, some users reported delays in voice synthesis and occasional contextual misunderstandings, indicating a need for technical refinement and better conversational scaffolding.

Future research should include larger, more diverse populations and explore cross-cultural, multilingual deployments of *XR Exhibit+*. Longitudinal studies are needed to assess sustained engagement, learning outcomes, and the impact of repeated or collaborative visits. The system could also be expanded to support multi-user interactions, real-time co-exploration across physical and virtual spaces, and adaptive pathways based on user interests or prior knowledge. Finally, studies on cost-effectiveness and scalability across museum types are essential for broader adoption.

7 Conclusion

This study introduced *XR Exhibit+*, an AI-enhanced XR museum guide grounded in constructivism and connectivism learning theories, designed to enhance engagement, learning, and emotional connection in both physical and virtual museum settings. Our findings show that *XR Exhibit+* significantly outperforms traditional approaches in key experiential dimensions, with no significant difference between AR and VR implementations, highlighting the system's cross-context usability and pedagogical robustness. By integrating annotated tooltips, LLM-driven conversational agents, user-generated reflections, and a semantic exhibit network, *XR Exhibit+* fosters a personalized and socially enriched learning experience. Qualitative feedback further underscored the system's ability to reduce cognitive load and facilitate natural, meaningful interaction with cultural content. Despite the promising results, the study acknowledges limitations related to sample diversity, exhibit scope, and long-term impact. Future work should focus on expanding the user base, exploring broader cultural contexts, and developing adaptive, collaborative, and multi-user experiences. *XR Exhibit+* serves as a compelling example of how theory-informed, AI-enhanced XR technologies can reshape museum learning, paving the way for more inclusive, interactive, and intelligent cultural engagement in the digital age.

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