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Exploring immersive cultural heritage experiences: a user study of a VR application featuring ancient manuscripts

Wenqi Li, Zeyang Luo, and Pengyi Zhang

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Abstract

Introduction. This study aims to explore how general users interact with and perceive cultural heritage through VR applications that feature ancient manuscripts. Specifically, it examines how VR experiences influence users' interests, knowledge acquisition, and engagement with cultural heritage, focusing on the effects of multiple information channels, plot structure, and VR device interactions.

Method. This study employs a mix-method user study design in which 37 participants were asked to explore the VR application featuring the Qing Dynasty manuscript, 'Nan Huai ren Ti Ben'. Data was collected through pre-task and post-task questionnaires, VR screen recordings, and interaction maps created by the participants.

Analysis. We conducted thematic analysis on the qualitative data and complemented with descriptive and inferential statistical analyses of quantitative data.

Results. The VR application effectively piques users' interest in the cultural heritage, including its historical and social context, and current state. Key design suggestions include integrating narration with other information channels, allowing for a balance of guided and exploratory interactions, and optimizing device interfaces for cultural heritage contexts. The study also proposes a design framework applicable to the broader VR cultural heritage field.

Conclusion. This study proposes a design framework and suggestions for VR cultural heritage, highlighting user needs, information channels, plot structure, and device interactions.

Introduction

Digital cultural heritage refers to the use of digital media to preserve, research, and communicate tangible and intangible cultural heritage objects (Münster, 2019). Digital cultural heritage brings significant benefits to education, research, and tourism, as it improves access to and deepens understanding, and appreciation of the rich and diverse heritage of different cultures and regions. Among different forms of digital media, virtual reality (VR) technology has been used in many contexts to create immersive and interactive environments that simulate real or imagined scenarios. By incorporating multiple sensory elements like visuals, sound, and touch, VR elicit users' sense of presence and realism (Nugent, 1991). It has now been widely applied in various domains, such as entertainment and gaming (Hsu and Liang, 2021; Liu et al., 2021), education (Greene & Groenendyk, 2021), and health care (Geng et al., 2024). VR also holds great potential for digital cultural heritage (Bekele & Champion, 2019), offering novel and engaging ways for users to experience and learn about the heritage in a virtual setting (Liu et al., 2021; Liu et al., 2022). For instance, VR can recreate historical scenes and events, allowing users to witness and engage with the past (Ch'ng et al., 2020), or simulate the deterioration process of heritage objects, raising awareness of their fragility and value (Fu et al., 2020).

Despite these promising applications, there are still some challenges and gaps that need to be addressed. Most existing studies have focused on VR's role in heritage presentation, education, and conservation. (Lo et al., 2019; Fu et al., 2020; Liu et al., 2021), there is limited understanding of how to design more effective VR experiences that align with the unique characteristics of different heritage forms and users' interests. Particularly, few research focused on VR experiences with ancient texts, such as rare books, archives, and ancient manuscripts. Ancient texts carry great historical and cultural value, yet they remain largely inaccessible due to physical and institutional barriers. This lack of accessibility further highlights the need for innovative VR applications that can bridge the gap between these texts and the public. Therefore, it is essential to explore how VR can make ancient texts more accessible and publicly engaging.

In this study, we aim to address this gap by exploring the following research question: How do general users engage with the VR application featuring ancient manuscripts? We conducted a mixed-methods user study with 37 participants who explored the historical contexts and cultural significance of the Qing Dynasty manuscript 'Nan Huai ren Ti Ben' using a VR application. Data were collected through pre- and post-task questionnaires, interaction videos, and user-generated interaction maps to understand the immersive experience. We examined various aspects that contributed to users' holistic experience, including the alignment of content with users' topical interests, the effectiveness of multiple information channels, the impact of plot structure on engagement, and the quality of interactions with VR devices. Based on the results, we provided design recommendations to optimize VR experiences for ancient manuscripts and similar cultural heritage.

Related work

Digital cultural heritage

The preservation and promotion of cultural heritage have benefited from the continuous advancement of digital technologies. Various forms of digitization not only broadens public access to cultural heritage (Davidson & Reid, 2021) but also enhances its overall accessibility and discoverability (Liew et al., 2021). The growing interest in digital cultural heritage has created new opportunities for the long-term development of cultural memory institutions, such as libraries, museums, and archives (Rasmussen, 2019). Recent advancements in computer vision, machine learning, and other AI techniques have attracted increased attention for their growing potential in digital cultural heritage (Ali et al., 2023; Hannaford et al., 2024).

Researchers studied human-cultural heritage interactions to propose digital solutions and principles that can support the preservation and transmission of cultural heritage (Lu et al., 2019; Schofield et al., 2019; Claisse et al., 2020; Pretto et al., 2020; Strousopoulos et al., 2023). Widely adopted digital practices include online databases, knowledge bases, digital collections, visualizations (Windhager et al., 2018), and the recreation of cultural heritage in VR and augmented reality (AR) (Tan et al., 2020; Z. Liu et al., 2022). Gamification is also a popular approach to engage the general public (Nofal et al., 2020), including narrative games (Antonioni et al., 2013) and adventure games (Fazio & Turner, 2020; Lehto et al., 2020; Y. Liu et al., 2021). However, most of these studies focused on cultural heritage readily accessible to the public, such as ancient relics (Petrelli et al., 2016; Cisternino et al., 2021), and artifacts in museums (Coenen et al., 2013; Pirbazari & Tabrizi, 2022). Limited attention has been paid to ancient texts, including rare books, manuscripts, archives, and oracle bones, which were usually preserved out of public reach.

Meanwhile, the development of digital cultural heritage presents a multitude of practical challenges that must be addressed. These include contextual barriers to information interaction, such as the availability of tools and resources, available time, and focus formulation (Kumpulainen & Late, 2022), as well as copyright issues (Stobo et al., 2018; Valeonti et al., 2019), cultural biases, and a discrepancy between the promises of emerging technologies and their current effectiveness (Sobotkova et al., 2024). Achieving this effectiveness requires the careful selection and design of approaches that accommodate diverse user needs and interaction requirements (Windhager et al., 2018; Torsi et al., 2020). With limited attention on digital experiences involving ancient texts, little is known about user needs or experiences in this area.

Virtual reality application in cultural heritage

VR technology offers the advantage of integrating visual, auditory, and other sensory channels to create a sense of presence and enable realistic interactions. Researchers have extended its application and examined its utility in various fields, including education (Petersen et al., 2021; Ma et al., 2022; Jin et al., 2022; Young et al., 2023; Hulusic et al., 2023; Wu et al., 2023), professional training (Teras et al., 2016), and scene simulation (Kelly et al., 2021; Reichherzer et al., 2021), among others.

In digital cultural heritage, VR's immersive interactive experiences and sense of presence can elevate users' engagement with cultural heritage to new levels (Bekele & Champion, 2019; Fu et al., 2020; Kumar et al., 2023). Previous research found that VR exhibits positive impacts on experiencing and learning about cultural heritage. For example, VR can recreate history in an interactive way to provoke users' interest in learning about cultural heritage in museums (Ch'ng et al., 2020). VR is also more effective regarding intangible cultural heritage applications, for it allows users to interact in a more immersive and authentic way compared to traditional web-based approaches (Selmanović et al., 2020).

In this new multisensory, immersive, cross-media era of reading (Robinson, 2015), VR is demonstrating its potential in reading promotion, particularly empowering the general public to read ancient books. Earlier studies have explored using VR or AR to facilitate the preservation and improve the reading experience of ancient texts (Parhizkar & Zaman, 2009). Davardoust et al. (2016) created scenes from a rare book through VR to let users immerse in contextualized experience. Zhang et al. (2021) developed a VR reading system for Chinese ancient books, integrating multimedia materials related to meta-knowledge of the content to reduce users' comprehension barriers. However, these works have primarily focused on reading experiences, little research has harnessed multiple sensory channels, such as audio and haptic feedback in VR, to convey information and create engaging digital experiences with ancient texts.

Sonnenwald and McElligott (2017b, 2017a) have explored how university students interact with rare books in physical settings and identified a complex process composed of interactions with multiple

sensory channels. They suggested that interactions with rare books can raise curiosity about the book's design and technology as well as individual and social practices of people who were connected to the book, such as the author, the first owner, and users. Introducing new fine-grained haptic feedback, audio, and olfaction to VR systems would allow users to experience rare books to a fuller extent. Furthermore, incorporating game-based interactions within VR can enhance participants' enjoyment and interactive experiences. Such approaches found to be more effective than traditional reading in facilitating learning (Liu et al., 2022). Therefore, it is worth exploring whether integrating different sensory channels and game-based interactions in VR can meet users' needs when interacting with ancient texts. This gap in fully leveraging VR's capabilities for ancient texts underscores the need for further investigation into user requirements and design solutions in this domain.

Methods

Research settings

The VR application '*journey through ancient manuscripts*' is an interactive documentary that recreates four significant historical discoveries of ancient manuscripts in China: Oracle Bones from the Yin Ruins, Han Bamboo Slips from Juyan, Dunhuang Manuscripts, and Ming-Qing Manuscript Archive. For this research, we used the Ming-Qing Manuscript Archive episode focusing on '*Nan Huairen Ti Ben*', which was released in March 2023. In the historical context of the Ming and Qing dynasties, '*Ti Ben*' refers to formal written reports or documents submitted by high-ranking officials to the emperor, addressing matters related to governance, policy, and significant state affairs. '*Nan Huairen Ti Ben*' is one such manuscript, documenting celestial phenomena records submitted to Emperor Kangxi by Nan Huairen, a Belgian missionary, and the Chief of the Imperial Astronomical Bureau. This VR episode immerses users in the role of a Qing Dynasty astronomer through a combination of visual, auditory, and interactive experiences (Figure 1). Users are first introduced to a brief historical background, then engage with historical contexts and participate in three interactive mini-tasks designed to enhance learning and engagement, including celestial observations (mini-task 1), star chart connection (mini-task 2), and manuscript composition (mini-task 3). The application then closes with remarks on the historical and society significance of "*Nan Huairen Ti Ben*".

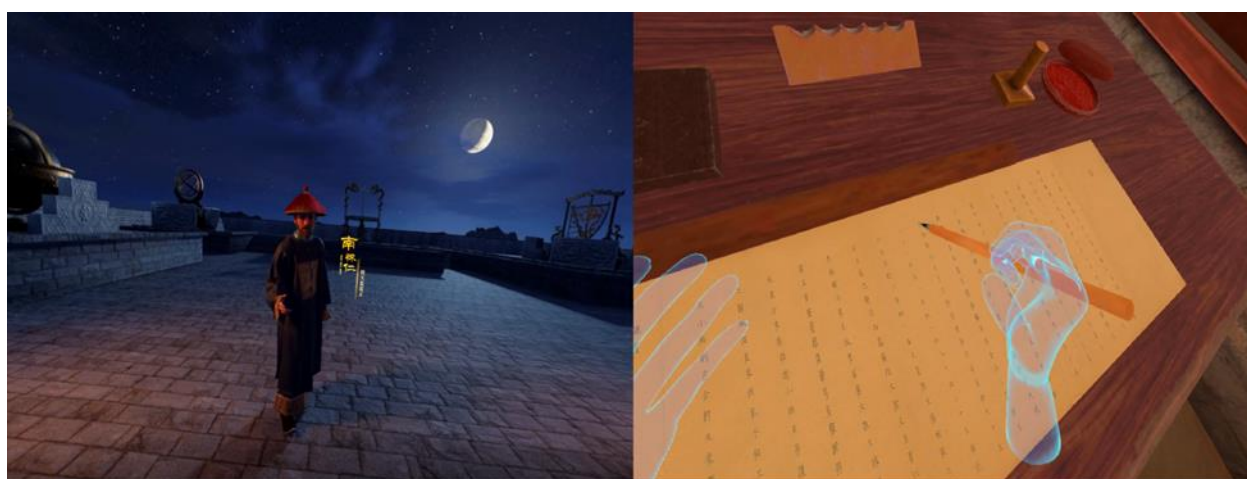


Figure 1. Screen Shots of VR application featuring '*Nan Huairen Ti Ben*'

We employed a mixed-methods user study design to investigate users' interaction behaviors and problems encountered when exploring a VR application of a Chinese manuscript, '*Nan Huairen Ti Ben*' (referred as '*the VR application*' hereafter). We targeted younger generation in participant recruitment, since this application was designed to promote traditional Chinese culture to the public, particularly young people with limited prior knowledge or interest in such cultural heritage.

We recruited a total of 37 undergraduate students from an HCI course, including 16 males and 21 females, all aged between 18 and 25. All participants provided informed consent prior to participation. According to the pre-task questionnaires, none of the participants had prior knowledge of ‘Nan Huaiaren Ti Ben’, ensuring that their experiences were unbiased by previous familiarity with the subject matter. Participants were asked to explore the VR application using the PICO VR headset and controllers, and then document their interaction flows and experiences in the form of an ‘interaction map’. We also collected video recordings of the interaction process.

Procedure

The study was conducted from March 20 to April 12 of 2023 and was approved by the Internal Review Board (Approval No. A130003). Participants individually signed up for one-hour sessions to complete the interaction tasks. Upon arrival at the lab, participants were greeted and provided with a brief overview of the study’s objectives and procedures. Researchers demonstrated how to properly wear the VR headset and use the controllers, after which participants were given time to adjust the fit, practice basic interactions, and optionally explore a simple virtual environment. This familiarization period was designed to minimize potential technical difficulties and ensure that participants could fully engage with the VR application without obstacles. Figure 2 shows participants interacting with the VR devices.

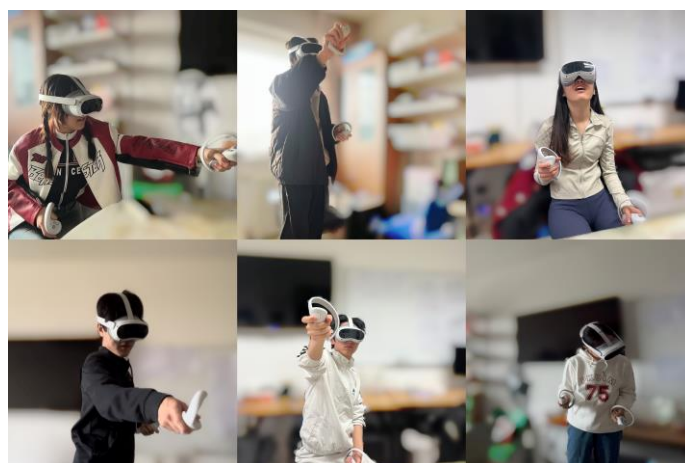


Figure 2. Participants Interacting with VR devices

Before engaging with the VR application, participants completed a pre-task questionnaire designed to assess their initial familiarity with VR technology and the topic of ‘Nan Huaiaren Ti Ben’. The questionnaire included a Likert scale rating for topic familiarity, a rating for VR familiarity, and an open-ended question asking what aspects of ‘Nan Huaiaren Ti Ben’ they were interested in learning about.

Following the completion of the pre-task questionnaire, participants put on the VR headset and initiated the ‘Nan Huaiaren Ti Ben’ episode within the VR application. The VR experience began with an introduction scene that set the historical context, using a combination of visual and auditory narratives to immerse the user in the Qing Dynasty era. Participants were guided through the virtual environment, where they engaged with the three interactive mini-tasks. During the VR experience, the headset’s built-in recording function captured participants’ screen activity. This recording provided a comprehensive view of their interactions within the virtual environment, including their navigational choices, engagement with interactive elements, and any exploratory behaviors exhibited.

Upon completion of the VR experience, participants removed the headset and proceeded to fill out the post-task questionnaire. This questionnaire measured changes in familiarity with the ‘Nan

Huairan Ti Ben,’ assessed knowledge acquisition through factual questions, and elicited participants’ perceived learning outcomes and topics of further interest. Both pre-task and post-task questionnaires can be found in © CC-BY-NC 4.0 The Author(s). For more information, see our Open Access Policy.

Appendix I.

After the lab session, participants were provided with the screen recordings of their VR experience. They were instructed to create an interaction map as part of their assignment. The interaction map was intended to document their interaction flows and experiences, as well as demonstrating their understanding of the functionalities and interactions within the VR device and application. Participants were encouraged to illustrate the sequence of actions using visual elements such as screenshots or diagrams. They also annotated any interaction pain points, challenges, or notable observations encountered during the VR experience. An example of an interaction map created by a participant is shown in Figure 3.

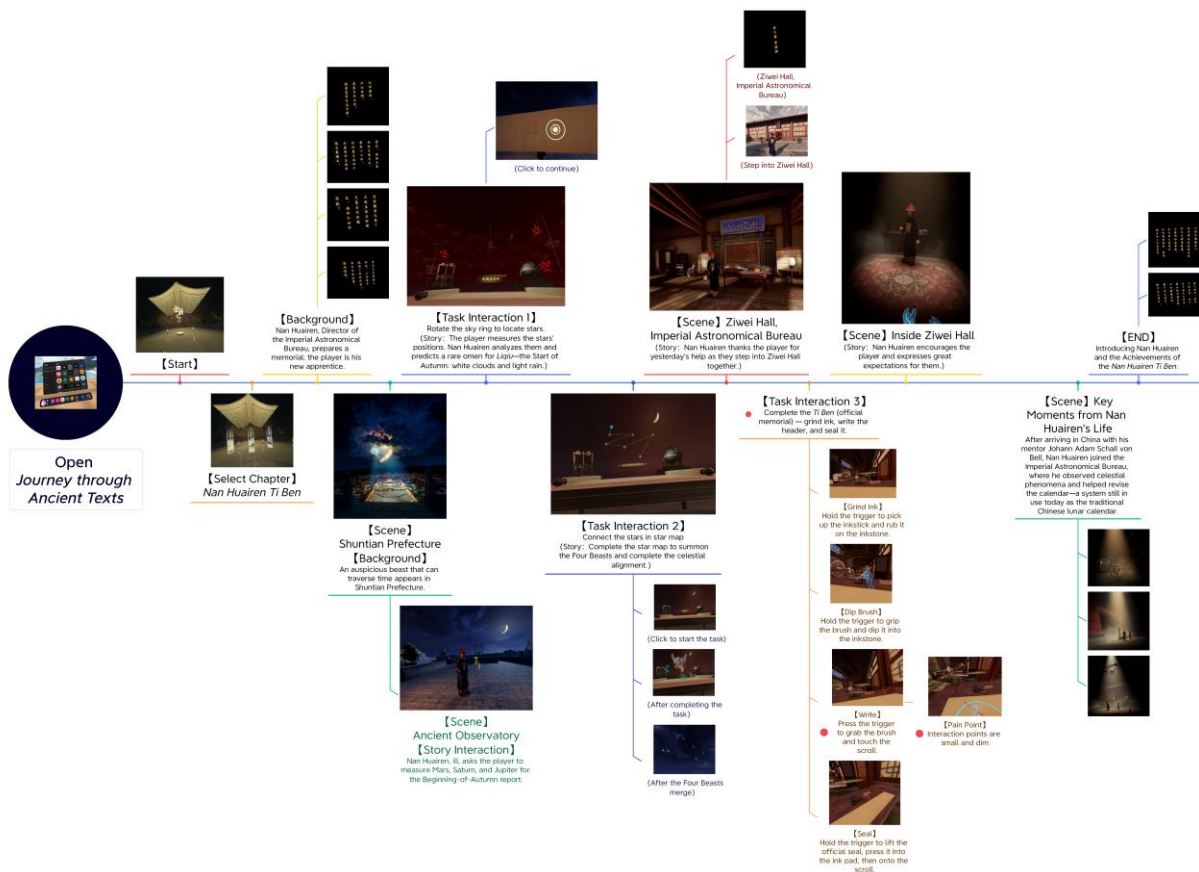


Figure 3. Interaction map of the 'Nan Huairan Ti Ben' episode in the VR application *Journey through Ancient Manuscripts*, created by a participant and translated by authors.

Data analysis

We first conducted thematic analysis (Braun et al., 2019) on the qualitative materials, including: open-ended responses of the questionnaires, VR screen recordings, and pain points annotated in interaction maps. Two researchers independently coded different portions of the data inductively. Throughout the coding process, the team held regular meetings to compare codes and discuss emerged themes. The inductive coding revealed four themes: interests in cultural heritage,

effectiveness of multiple information channels, the interplay between guided plots and free exploration, and user experience with VR devices.

To complement the qualitative findings, we also performed descriptive statistical analyses on the participants' self-reported familiarity with 'Nan Huaiaren Ti Ben' before and after the VR experience. This assessment quantified changes in their perceived knowledge levels following the VR experience. Then, participants' answers to factual questions in the post-task questionnaire were evaluated for accuracy to assess knowledge acquisition. Each response was scored based on correctness and completeness: 10 points for fully correct answers, 5 points for partially correct answers, and 0 points for incorrect answers. This provided extra support for the findings on the effectiveness of multiple information channels as the VR application used different information channels (combinations of text, visuals, narration, and interactions) to convey relevant content.

Findings

Users' topical interests in cultural heritage

We categorized the topical interest expressed by participants in pre-task and post-task questionnaires into three categories:

- ⑩ **Object and Character:** Interest in the content of the manuscript and historical figures associated with it.
- ⑩ **Historical and Social Contexts:** Interest in the historical period, cultural background, and societal significance of the manuscript.
- ⑩ **Current State:** Interest in the preservation, technological aspects, and contemporary relevance of the manuscript.

Comparing pre-task and post-task responses allowed us to determine whether participants' curiosity about different facets of the manuscript and its context had changed after experiencing the VR application. As shown in Table 1, object and character interest accounted for the largest proportion in both pre-task and post-task conditions. The number of participants interested in this category remained largely stable, with a minor increase. Participants' post-task topical interest, as expressed through their questions, became noticeably more focused and concrete than their pre-task interest. Meanwhile, the number of participants interested in historical and social contexts also increased after the VR experience. This suggests that such a VR experience can provoke users' interest in cultural heritage, fostering a desire to acquire more related knowledge and prompting them to reflect more deeply on the social aspects.

Category (% of Participants)	Pre-task Examples	Post-task Examples
Object and character (73%→78%)	P6: Who is Nan Huaiaren?	P18: The specific process, tools, and methods of celestial observation he adopted.
	P9: What is a Ti Ben?	P13: Why did he come to China, and would he be alienated as a foreigner?
historical and social contexts (27%→41%)	P15: What is the social significance of Nan Huaiaren Ti Ben?	P3: How have later generations inherited and developed his career?
	P27: What is the historical background of its creation?	P35: The historical achievements of ancient Chinese astronomy and comparison to the West.
Current state (22%→16%)	P14: How is it preserved and circulated?	P1: Where is the original manuscript preserved?
	P4: Related research	P12: Other VR applications of similar topic.

Table 1. Categorized topical interest reported in the questionnaires

In comparison, participants reported less interest in the current state of 'Nan Huaiaren Ti Ben'. This was likely because the VR application did not introduce its current state. However, several participants expressed their curiosity and interest in more VR applications and technologies on similar topics. One participant explicitly mentioned that he looked forward to more similar interactive experiences involving haptic feedback.

Based on participants' ratings on a five-point Likert scale assessing their familiarity with 'Nan Huaiaren Ti Ben,' all participants initially indicated complete unfamiliarity with the subject. Following the VR experience, participants reported a certain level of increased understanding, with the vast majority rating their familiarity as 3 or 4. This indicates that the VR experience can, to some extent, improve users' understanding of the topic. Combining the reported topical interest and the actual VR application design, we noticed that the VR experience focused primarily on a factual introduction to the topic, which was an easy start to arouse users' interest. Yet it presented very little on the historical or social contexts or significance, nor did it reflect how the manuscript was circulated and preserved today.

Effectiveness of multiple information channels

The VR application combined multiple channels, including texts, visuals, narration, and interactions, to convey information about 'Nan Huaiaren Ti Ben'. To evaluate the effectiveness of these information channels in facilitating users' knowledge acquisition, participants were asked five factual questions—each associated with content of varying length—after the VR experience. The average scores for these questions, along with the information channels through which the relevant information was conveyed, are presented in **Figure 4**.

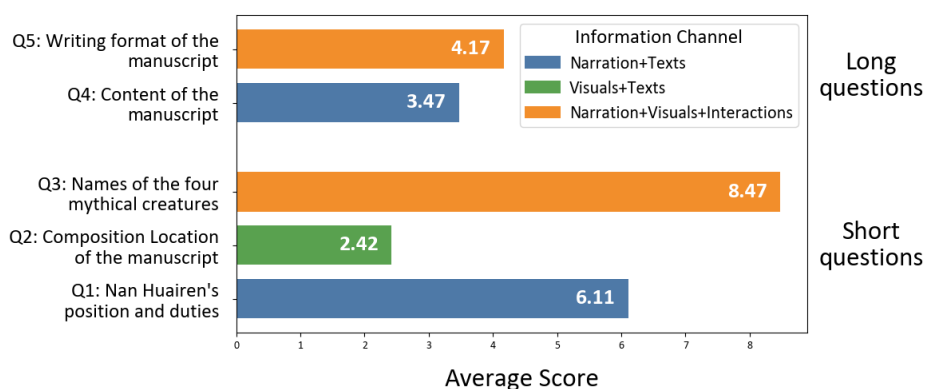


Figure 4. Average scores of factual questions conveyed with different information channels

We conducted Friedman Test to determine whether the differences in average scores among questions were statistically significant. The test revealed a statistically significant difference in scores across the five questions ($\chi^2(4) = 50.878, p < 0.001$). This indicates that the effectiveness of users' knowledge acquisition varied depending on the combination of content length and information channels used in each question. To identify which specific pairs of questions differed significantly, we conducted post-hoc pairwise comparisons, using the Wilcoxon Signed-Rank Test with a Bonferroni correction (adjusted significance level $\alpha = 0.005$).

Among the five questions, Q2 scored the lowest average (2.42 out of 10). Particularly, it scored significantly lower than the other two short questions Q1 ($p < 0.001$) and Q3 ($p < 0.001$). Notably, it was the only question where relevant information was conveyed without narration, relying solely on visuals and text. This suggests that narration plays a critical role in effectively communicating information in VR experiences. Without the auditory channel, participants may find it more challenging to process and retain the information presented.

In contrast, Q3 achieved the highest average score (8.47) and differed significantly from the other two short questions Q1 ($p<0.001$) and Q2 ($p<0.001$). Similarly, between the two longer questions, Q5 scored slightly higher than Q4 ($p=0.34$), though not significant. Both Q3 and Q5 utilized multiple information channels in combination, including narration, visuals, and interactions, which contributed to the effectiveness of information communication. This indicates that incorporating interactive visual elements alongside narration can improve users' comprehension and retention of information in VR environments. Further, the results also revealed significant difference between Q1 and Q4 ($p=0.001$) as well as Q3 and Q5 ($p<0.001$). Both pairs share the same information channels but differed in length, that longer information increases cognitive load for users in the VR environment.

Though previous research has found that the combination of multiple channels is considered more effective than a single channel (Allport et al., 1972), these channels might also interfere with each other. In the interaction maps, quite a few participants mentioned that they paid too much attention to visuals or texts thus did not hear the narrations clearly. For example, Participant 13 stated, *'The visuals were captivating and diverted the majority of focus, failing to listen to the narrations.'* Participant 31 mentioned, *'The texts on the manuscript are too small. I tried hard to read them, which resulted in not hearing the narrations at all. And I don't think such textual contents can be conveyed clearly through narrations alone.'* The feedback implies that among the competing channels, visual channels, including visuals and texts, tend to draw more attention than auditory channels like narrations.

As another example of this effect, in the answers of Q3, the correct names of the mythical creatures were given in the narration – 'Zhu Que (vermilion bird)', 'Xuan Wu (tortoise entwined with a snake)', 'Qing Long (azure dragon)', 'Bai Hu (white tiger)'. However, many participants referred to 'Zhu Que' as a phoenix, 'Xuan Wu' as a tortoise, and 'Qing Long' as a snake or deer. These answers were clearly based on the visuals instead of narrations. This example not only indicates that visual channels are more attractive than auditory channels, but also that texts are necessary for the precise communication of information. Many participants emphasized in the interaction maps that texts are important for accurate memorization of core information, stating that narration alone is insufficient.

Interplay between guided plots and free exploration

The VR application is structured as a guided interactive documentary, where the narration is provided to set the context and make introduction and comments, while the guidance on interactive mini-tasks is conveyed through conversations with the main character Nan Huairan.

By coding the screen recordings, we observed that most free exploration occurred at the beginning of the experience or during scene transitions, where users scan the surroundings and interact with different visual elements using controllers. For instance, during the 'introduction' stage, some participants explored the starry sky by looking up and down from various angles. In mini-task 3, some participants attempted to interact with the mythical creatures on the table by trying to grab them using controllers, and some tried to lean closer to read the manuscript details while composing. However, due to the progression of the storyline, these interactions tend to be relatively brief.

Many participants expressed dissatisfaction with the lack of interactivity and exploration freedom in their interaction maps. Participant 11 mentioned that *'One can only observe the actions of the main character and is unable to actively participate in interactions with the character'*. They described the experience as 'passive' or *'like watching a video with minimum proactive interaction'*. Participant 11 also mentioned that during mini-task 1, the guiding narration was interrupted when she tried to interact with a visual element out of curiosity and there was no way to replay the guidance. Moreover, some participants expected to examine the manuscript in detail but felt

rushed during the exploration. This finding echoes previous research - the compact plot arrangement and constant guidance facilitate the progression of the story but may limit users' opportunities for unexpected interactions and free exploration that can be conducive to their engagement (Liu et al., 2021).

User experience with the VR devices

Almost all participants reported pain points with the headset and controller interaction in the interaction maps. We identified several pain points specific to reading the manuscript besides some common issues such as discomfort during prolonged use, inconvenience for people wearing glasses, and limitations in performing fine movements.

First, in the relatively vast VR landscape, both Nan Huaiaren's figures and texts appeared distant and small, making it challenging to see them clearly. Some participants felt compelled to tilt their bodies or lean over, although these actions did not bring them closer to the objects. Second, when people read, there tends to be a slight natural movement of the head from left to right. However, VR's sensitivity to head movement caused the view to move along with it, resulting in a decrease in reading speed and blurred vision. Third, in mini-task 3, participants were expected to simulate the actual act of writing in a manuscript with the controller. However, the design of this application only required triggering an interaction point with one button click to generate text. This difference from actual writing led to a lack of realism and haptic feedback.

Discussion

A design framework for VR cultural heritage experiences

Drawing from the findings, we propose a design framework for VR cultural heritage experiences that aims to balance between user engagement and effective information communication (Figure 5).

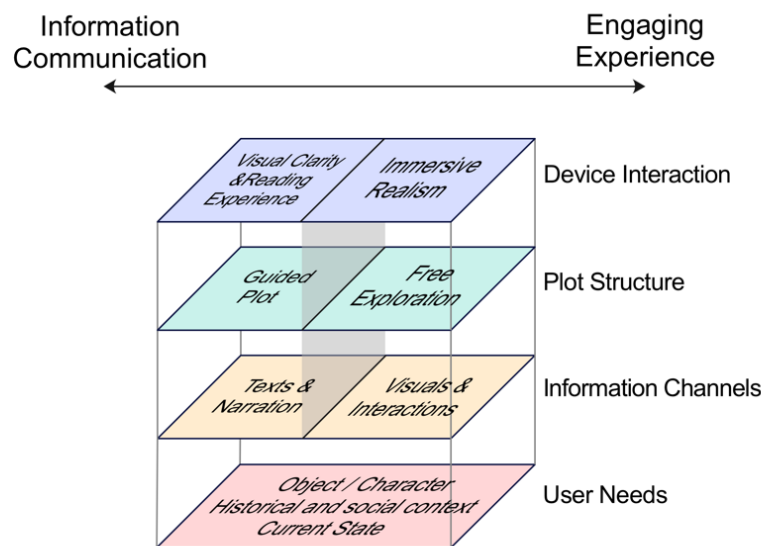


Figure 5. Design framework for VR cultural heritage experiences (Adapted from Garrett, 2000)

Adapted from 'the elements of user experience' (Garrett, 2000), the framework consists of four hierarchical layers, each representing a component of user interaction with VR cultural heritage.

At the foundation of the framework is the 'user needs' layer, which emphasizes understanding the user's interests and the relevance of the content. This layer addresses the core elements of the

cultural heritage being explored — an object or a character, and its historical, social, and contemporary contexts. This extends Sonnenwald and McElligott's framework, which identified curiosity about book design and individual and social practices when interacting with physical rare books, by adding the 'current state' aspects (Sonnenwald and McElligott, 2017a). Grounding the VR design in these topical areas ensures that content aligns with the user's informational needs.

The second to fourth layers are oriented towards balancing the two objectives: users' engaging experience and effective information communication. Each side of these layers reflects a different focus, guiding how content is structured and presented to the user. The second layer, '*Information Channels*,' is split between texts and narration, which are important to effective information communication, and visuals and interactions, which add more to engaging experience. Text and narration provide clear, factual information, facilitating accurate comprehension, while visuals and interactive elements seek to immerse users more deeply, capturing attention and stimulating curiosity. The third layer, '*Plot Structure*,' similarly balances these two objectives. A guided plot, which offers a structured, linear narrative that ensures users receive key content in a cohesive and digestible format, can communicate information more efficiently. On the other hand, free exploration, aimed at enhancing engagement, gives users the freedom to navigate the VR environment at their own pace. This non-linear approach caters to those who prefer to explore content spontaneously, fostering a sense of discovery and personalization. The fourth layer is '*device interaction*'. To effectively communicate information, device should ensure visual clarity and a smooth reading experience, so that users can easily access and absorb information without distraction. Conversely, immersive realism emphasizes engaging experience, creating a convincing digital environment that draws users in and encourages emotional and sensory involvement. This layer thus not only focuses on content accessibility but also on enhancing user immersion in the virtual environment.

In summary, the design framework harmonizes user needs, information channel, plot structure, and interaction design to build a more engaging and effective VR experience for cultural heritage. Design decisions over these elements can be made considering the objective of the experience, whether to communicate information more effectively or to emphasize user engagement.

Design implications

Based on the proposed framework and findings in our study, we derived concrete design implications for effective VR cultural heritage experiences.

Regarding user needs, firstly, it is crucial to include both the past and present aspects of the cultural heritage subject. By incorporating information such as preservation efforts, ongoing research, and current exhibitions, VR experiences can bridge the historical context with contemporary relevance. This approach enriches the user's understanding and fosters a connection between the historical artifact and its significance today. Secondly, designers should capture users' potential points of interest by progressively delving deeper into specific objects or characters while also providing a broader historical context beyond specific details. This will satisfy users' curiosity and promote a more comprehensive understanding of the cultural heritage topic, catering to both novice users and those seeking in-depth knowledge.

In terms of information channels, while visuals and interactions are effective in enhancing knowledge acquisition, it is essential to maintain a balance to avoid overshadowing auditory cues that support user engagement. Our findings indicate that when visual elements dominate, users may miss important information conveyed through narration. Meanwhile, legible text should be included to complement auditory information for precise communication of critical details.

Regarding plot structure, balancing guided narratives with opportunities for free exploration is key to increasing user agency and engagement. Keep the guided narrative for valuable information but

allow more free exploration during non-critical moments to increase users' sense of immersion and personal connection to the content. Offering additional time and interactivity for an in-depth examination of cultural heritage artifacts can deepen users' understanding and appreciation, making the experience more memorable and impactful.

Addressing device interaction issues is also crucial, particularly for VR experiences rich in textual content. Optimizing the visual clarity of texts and main characters or objects in the expansive VR environment is essential to prevent users from straining or becoming disengaged. Introducing features such as a head movement lock can prevent the entire VR view from shifting with users' subtle head movements, ensuring a stable and comfortable reading experience. Moreover, enabling users to simulate actual writing, painting, or other crafting experiences—beyond mere clicking and grabbing interactions—can provide haptic feedback and a greater sense of immersion, leading to more authentic and satisfying interactions.

Conclusion

The study examined user interactions with a VR application focused on an ancient manuscript, shedding light on several critical aspects of the design of VR cultural heritage experiences. A design framework and a set of concrete design suggestions were proposed for more engaging and informative VR cultural heritage experiences. As this is a preliminary exploratory study, we expect more rigorous experiments in the future to validate the topical interest categories and effectiveness of varying information channels and plot structure designs. By considering users' evolving interests, effective communication strategies, engagement dynamics, and interaction enhancements, we can create more immersive, informative, and engaging VR experiences that foster a deeper appreciation and understanding of cultural heritage.

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About the authors

Wenqi Li is a Boya postdoctoral fellow in the Department of Information Management, Peking University, where she received her PhD. in Information Science. Her research interests include digital cultural heritage, data behavior, and human-computer interaction. She can be contacted at wenqili@pku.edu.cn.

Zeyang Luo is a master's student in the Department of Information Management, Peking University. Her research interests include user information behavior and cognition, human-computer interaction, and user experience—particularly in the contexts of digital humanities crowdsourcing and digital cultural heritage. She can be contacted at lzeyang@stu.pku.edu.cn.

Pengyi Zhang is an Associate Professor in the Department of Information Management, Peking University. She received her PhD in Information Studies from University of Maryland. Her research focuses on information and knowledge organization, information behavior and data behavior, and user-centered design and evaluation. She's the corresponding author of this paper and can be contacted at pengyi@pku.edu.cn.

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Appendix I

Pre-task questionnaire

1. Name:
2. How familiar are you with the use of VR (Virtual Reality)?
(Please rate on a scale of 1 to 5, where 1 = Not familiar at all and 5 = Very familiar)
3. What knowledge do you possess regarding the topic of the ‘Nan Huaiaren Ti Ben’?
4. To what extent do you consider yourself familiar with the themes related to the ‘Nan Huaiaren Ti Ben’?
(Please rate on a scale of 1 to 5, where 1 = Not familiar at all and 5 = Very familiar)
5. If you were to conduct a search on the relevant topic, what specific questions would you like to investigate?

Post-task Questionnaire

1. After the above VR experience, what new understanding do you have about the ‘Nan Huaiaren Ti Ben’?
2. How familiar do you consider yourself with the themes related to the ‘Nan Huaiaren Ti Ben’ after the VR experience?

(Please rate on a scale of 1 to 5, where 1 = Not familiar at all and 5 = Very familiar)

3. What other related topics would you like to continue exploring or researching?
4. The duties and responsibilities of Nan Huai ren are:
5. The main content of the 'Nan Huai ren Ti Ben':
6. The writing format of the 'Nan Huai ren Ti Ben':
7. The year and location where the 'Nan Huai ren Ti Ben' was written:
8. The four mythical creatures summoned in the game and their corresponding positions:
Top— [], Bottom—[], Left—[], Right—[]
9. Describe what content you searched for and what new insights you gained.
10. After conducting your search, how familiar do you consider yourself with the themes related to the 'Nan Huai ren Ti Ben'?

(Please rate on a scale of 1 to 5, where 1 = Not familiar at all and 5 = Very familiar)