The Effects of VR Environments on the Acceptance, Experience, and Expectations of Cultural Heritage Learning

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This article attempts to understand how present Virtual Reality (VR) environments can contribute to enhancing the communication of cultural heritage by providing an experience of the past that is acceptable for the younger generation and how museums and cultural institutions should adopt and use such technologies. Aspects of acceptance, experience, and expectation of VR with the underlying values are not well understood but are important for the sustainability of the communication of cultural heritage as a bequest to future generations. We conducted a combined quantitative–qualitative study on the participants who have various prior experience with gaming and VR, and different levels of knowledge on the history presented within the virtual environment. This study investigates how participants accept and are stimulated in terms of personal experience and their expectations and ideas for the future of museums if VR is used for enhancing the learning of cultural heritage. Prior gaming and VR experience were investigated to see whether they do indeed influence the preference for using VR for learning cultural heritage. We demonstrated that particular age groups and background are especially agreeable to virtual reality as environments for learning and experiencing cultural heritage, regardless of their knowledge of the historical context of the virtually reconstructed site. Our findings also revealed important behaviours in our demographics group with regards to user preferred length of time and the believability of the virtual environment and how it influences aspects of their experience such as the exploration of the heritage site, familiarity, and meaning making. The study has implications for the use of VR for enhancing the experience of cultural heritage in museums and cultural institutions.

CCS Concepts: • **Human-centered computing** → **Virtual reality**; **User studies**;

Additional Key Words and Phrases: Digital heritage, virtual heritage, digital technology, virtual reality, technology acceptance

ACM Reference format:
Eugene Ch'ng, Yue Li, Shengdan Cai, and Fui-Theng Leow. 2020. The Effects of VR Environments on the Acceptance, Experience, and Expectations of Cultural Heritage Learning. *ACM J. Comput. Cult. Herit.* 13, 1, Article 7 (February 2020), 21 pages.
https://doi.org/10.1145/3352933

This work was carried out at the NVIDIA Joint-Lab on Mixed Reality and the Digital Heritage Centre. The authors acknowledge the financial support from the Science and Technology Department of Zhejiang Province (2017C33029), IAMET (2017D10035), Ningbo Science and Technology Bureau, and the International Doctoral Innovation Centre (IDIC).

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1556-4673/2020/02-ART7 $15.00
https://doi.org/10.1145/3352933

1 INTRODUCTION

Visiting museums and learning about cultural heritage can be likened to time travel, for we access the past via information gained and gleaned from ancient artefacts and sites, and through mediation are often transported via our imagination to the intended locale. The effects of textual and graphical mediation accompanying museum relics and how they affect transport and the experience of cultural heritage are rarely studied, and whilst imagination was briefly mentioned as one of the important factors accompanying interaction and immersion for presence in Virtual Reality (VR) [4], it has never been actually studied. Perhaps it needs not be studied at all, since Virtual Reality, i.e., capitalised and referring to the capability of technology for simulating virtual "reality" in present times can be truly immersive and engaging, involving full physical interaction and navigation and embodied as virtual avatars that could influence user cognition [2]. It is possible for mediated transport via textual and general media to be completely replaced by virtual reality, the ultimate media that can host all present media, with permutations of virtual worlds created for different scenarios of use, including the reconstruction of both the distant and the near past. We think that whilst present VR technology still lacks many aspects of reality, it can be used for reconstructing the visual aspects of entire worlds in any period of history, provided that archaeological information is available. As Pescarin noted, such technologies can help save our world's vanishing cultural heritage [41]. VR can also enhance scenarios with non-reality, or aspects of reality can be removed so as to reduce data noise in experiments. In this respect, VR has great potentials for communicating aspects of cultural heritage that are not possible with general media. If used properly, VR can communicate entire experiences that are lacking in present museum displays. As the constructivist theory stated, a meaningful context stimulates visitors' learning interest in constructing new knowledge [50]. It may also be a solution to the ongoing issue of the dwindling population of younger visitors interested in museums and ordained school trips [31].

In general, present museum displays and cultural heritage sites assign sections for objects, grouping artefacts according to their historical periods and contextualising them so that visitors acquire maximum information whilst saving space, a valuable resource in museums. The artefacts are often accompanied by captions, posters, and videos, and, if digital technology has been adopted, will be types of digital media displays for conveying deeper information. Although some museums re-enact historical scenes with physical models, the need to optimise the use of space resulted in exhibits that often lacked the experiential aspects of cultural heritage with regards to interaction with the scene. As a consequence, learning through experience does not occur [33]. We think that VR technology can afford experiential learning, as the contextual events and authentic tasks play a crucial role in "inviting" users into an active process of sense-making [30].

We believe that present VR technology is ready for adoption as a result of the accessibility of the devices and ease of development. What is not understood well is the suitability of VR technology for targeted users in terms of acceptance, experience, and expectations. Therefore, our aim in the present research is to recognise how VR environments can be used in such a way if VR were to be adopted by cultural institutions.

2 BACKGROUND

Cultural heritage must be made accessible and acceptable by the present younger generation with particular preferences for learning styles and preferential modes of accessing cultural heritage information. This is not well understood but is important for the sustainability of the communication of cultural heritage as bequests to future generations. The importance of cultural heritage [49] cannot be overstated and needs not be restated, for it contributes to both use value, in terms of economic growth, and intrinsic value, all at different levels of society [1, 16, 19, 23, 39, 42] and spanning countries [18].

One of the issues with present museums is the dwindling number of younger participants. Apart from scheduled school trips, studies suggest that visitor demographics were in the upper age range. One plausible reason is the distraction of media, and others were that parents were giving up taking their children to museums or rationing such visits. The UK's Department for Culture, Media and Sports [17] reported a decline in visitor

numbers, at 6.0%, a significant number considering that annual museum visitor population in the previous year was 47.7m. Child visits dropped to 7.9m, a 14.4% decrease from 2014 to 2015. Overseas visitors accounted for 47% of all visits, and the number fell by 1.4m from 2015 to 2016. The Museums Association also reported that the greatest decline was from educational visits and school groups; there was a 6.9% drop in children under 18 being taken on school trips and participating in workshops and educational activities in galleries and museums (from Reference [21]). This decline is mirrored in the US. The Survey for Public Participation in the Arts by the National Endowment for the Arts reported an overall decline of about 20% in art museum attendance from 2002 to 2012 [28, 29]. The American Academy of Arts and Sciences reported in its Humanities Indicators that there was a decline of 13% of Americans age 18 or older visiting historic sites and that Americans were 50% less likely to visit a historic site in 2012 as compared to 1982. It was also surprising to see a statement reporting that, "as people aged they were less likely to visit a historic site."

In contrast, there has been a slight annual increase of the number of visitors under age 18 in China since 2008; however, the percentage of this age group in all visitor has never reached 30%, ranging from 24% to 28%. There may be a reason for such growth [48].

China's mobile museums Apps are more developed than digital systems adopted in museums. Visitors register for events via museums' social media channels; mobile phones are used with QR codes to obtain media information from exhibits and to deliver cultural products in more creative and entertaining ways. Targeted audience reach is therefore broad. Recent use of documentaries to attract younger participants attracted 15,000 college students to apply for work at the Beijing Palace museum in 2016 [8]. Another documentary attracted 162.32m views on Tencent [47] and 78.25m in iQIYI [26], with audiences in the age group of 25 to 30 and the second most popular age group of 18 to 24 [27]. We felt that the potentials of new media types have not been fully tapped into.

Digital technology was thought to be attractive to younger visitors, and museums have seen an increase in the adoption of interactive digital media accompanying exhibits. These were multimedia access in the 1990s, multitouch displays around 2010, and Smartphone/Tablet Apps, VR, and Augmented Reality (AR) in more recent times. There appears to be a trend where any newly developed digital device is tested as a container of cultural heritage, making the historical contents and visitors "lab rats" of technology within the dimly lit recesses of exhibits. How well the application of digital technologies appeals to the wide range of audiences is not well understood, to say nothing about the suitability of such devices for both contents and visitor demographics, their acceptability, and their effectiveness for teaching and learning. Different digital technologies and interaction styles combined with heritage contents do produce different experiences. As such, any attempt at imposing a piece of technology as suited to all kinds of visitors is bound to be challenged by practitioners and subsequently rejected by users. A recent study spanning multiple museums over large geographical regions reinforces the need for more informed digital technology adoption [13]. There needs to be a balanced study, with digital devices being specific to the study, and with participants at another level of granularity, looking at the potency of the combination of technology and contents against user acceptability, the experience they can provide, and expectations. We believe that the understanding of the interface between technology and users necessitates both quantitative and qualitative interpretation. The quantitative aspects can reveal trends, and the qualitative aspect explains the reason.

Studies on how acceptable and effective digital technologies are with users have been conducted, but there is no conclusive evidence. Fortunately new technologies applied to cultural heritage has not stopped. Especially in the more curious academia, pioneering works continue to bring to light the potentiality of the transformative nature of digital technologies for cultural heritage. The integration of technologies with museum collections within exhibits is a process of constructing the museum from an elite and didactic institution to a more democratic learning space. Such practices align the needs of audiences with museum interpretation approaches by communicating with them via technologies [38, 53]. Most published research works are project oriented, with the aim of cultivating best practices for museums. These are the evaluation of touchscreen-based information kiosks for art museum [34], for history and archaeology museums [19], for research related to the qualitative evaluation of multitouch screens [10, 11], digital augmentation device [54], handheld guide device in historic

house [24], and a Mixed Reality installation for an art gallery [15]. These endeavours demonstrate the advantages of digital installations, for they provide contextual information together with enhanced interactions and engagement with exhibits [20]. At least with touchscreens, there was evidence of increased audience attention after use, with memory retention even after several months [20]. In a recent study [7], Augmented Reality was shown to be easy to master by children in terms of interaction and to trigger curiosity with the combination of virtual information and physical objects in museums. Evaluation of VR installations [3, 6] also suggested that immersive environments can be effective in communicating cultural contents, useful for attracting young people, even though at the time of the study, the use of "VR" was mostly panoramic, visual only devices, without interaction capabilities. Commercially available, true VR that supports natural interaction is likely to be more acceptable and can better engage young audiences. Technology coupled with content designs for supporting educational experience in museums are excellent combinations; this includes narratives, active interpretation, and engagement [25].

We believe that learning in museums should be not only based on the guided contextualisation of objects, but also that visitors should be allowed to construct their own individual interpretation of objects through interacting with the subject of interest and that virtual reality can afford such kinds of learning via a future constructivist learning approach. According to Vygotsky's constructivist learning theory [50], knowledge can come spontaneously from personal experiences that often occur in a non-systematic and informal approach. This theory emphasises that people learn best when they are allowed to construct a personal understanding by experiencing a process and reflecting on that particular experience. The experience of every individual is unique, and that specific experiences strengthen their existing understanding and enhance learning interests. We believe therefore that instead of the passive and voiceless learning approaches often witnessed in museums, VR can be used for it has both the technical facilities as well as the affordances of virtual spaces for building a constructivist environment, and this may be able to provoke in users further interpretations of history through the meaning and reality perceived by them. Within virtual environments, users are able to determine the selection of information and the focus of attention based on their prior knowledge and expectation. A constructivist environment can also trigger curiosity as users become more engaged in applying their existing knowledge and defining the meaning from their new findings.

Our survey [13] of 22 museums and cultural heritage sites over 15 cities suggests that digital technologies were not appropriately adopted by museums for the reasons stated above, particularly that there has not been a visitor-centred approach in the design of digital contents that are open to sustained individual experiences as well as the inclusivity for allowing multiple meanings to form. Our observations of 807 samples of visitors using a range of devices from multimedia interfaces, projection systems, and multitouch displays to VR and AR devices indicated very little contact time and engagement. The range of digital technologies adopted by museums was sadly, unsuited to different age groups. The issue here may be due to the inadequacy of museum resource. Whilst IT is core to 21st-century museums, the idea of investing in a digital team is not in the immediate plans of the majority of museums. This issue is echoed throughout the museum world in both the West [43] and the East [51]. A recent finding [43] reveals that the majority of museums have not embraced full digital maturity and that there was a significant underinvestment in digital skills although the idea of a digital team has become a part of their vision.

Why VR for cultural heritage and why now? Endeavours for Virtual Heritage in the late 1990s [44, 46] have been progressing for two decades. The original aim of Virtual Heritage was for non-intrusive access to cultural heritage sites [46]. The early days of the domain saw many reconstructions and some actual three-dimensional (3D) laser scans of sites integrated into VR systems for access, in fact, there were more reconstructions of models than there was actual VR experience. Not until the large corporate investment in the development of commercial VR headsets did the advancement of VR-capable Graphical Processing Units (GPU), and the accessibility of easy-to-use 3D modelling packages and integrated development environments become a feasible means for reconstructing believable heritage sites. Recent advances in photogrammetry techniques that made it possible for

heritage objects and sites to be captured via photo sequences have brought about another level of believability to virtual environments. Here, we define believability as the subjective perception of what the virtual environments can provide in terms of its visual realism as well as the sense of presence induced via various means, e.g, interaction, navigability, affordances, and and so on. This extends specificity to Gilbert's definition of VR "authenticity," which refers to "whether the virtual environment provides the experience expected by the user, both consciously and unconsciously" [22]. Cultural heritage of any periods can now be reconstructed. Our in-the-wild study [35] demonstrated the readiness of VR, affecting both users and observers alike. Present VR technology does lack many aspects of non-visual reality such as haptics, and so on. However, entire worlds, existing or lost, can be virtually recovered, allowing heritage sites and objects to be accessed from a distance in both spatial and temporal scales, and virtual time travel is becoming a possibility [9]. In this sense, VR has great potential for communicating aspects of cultural heritage. Recent works incorporating virtual reality as a means of accessing cultural heritage are witnessing trends in the creation of experiences of heritage environments and objects [12, 14].

3 METHODOLOGY

Our method covers the entire process of VR development, but a greater importance is posited in our experiments, as it is the main contribution of this article. Here, we provide our set of research questions based on the aim of our article, which investigates how virtual environments can contribute to enhancing the communication of cultural heritage to the younger generation, how it influences the acceptance, experience, and expectation of cultural heritage learning. Our overarching question is if virtual environments will have an effect on the acceptance, experience, and expectations of cultural heritage learning for our user demographics group (RQ0). We asked the following four sub-questions and provided further insights gleaned from our research questions that we present under Results, where we will conclude our research with a discussion of our findings.

- RQ1: Does prior gaming or the use and the experience of VR affect the acceptability of VR for the experiential learning of cultural heritage?
- RQ2: Does the believability of virtual environments and objects provide a means from which meanings and memories may be formed?
- RQ3: Do user curiosity and exploratory behaviours influence their experience of virtual environments?
- RQ4: Is prior knowledge a factor that influences the ability of VR users for detecting irregularities in virtual heritage sites?

3.1 VR Design and Research Rationale

We reconstructed an 800-year-old Yuan Dynasty site, *Sanjiangkou*, at the confluence of three rivers, the Yuyao River, Fenghua River, and Yongjiang River, within the ancient city of Ningbo. Structures of architectures were roughly similar, but objects were deliberately mixed from different time periods and geographical regions. The particular historical period was chosen, as they were unlikely to be familiar, which allows us to test our hypotheses. We further included cultural objects of different time periods so as to gauge how well participants recognised them in relation to their reported knowledge of the history. Using a distant historical site can inform us of the experience of virtual reality and how real participants may feel, particularly when the site does not have any great semblance to present cities or villages.

Is VR acceptable to our target age group regardless of their prior gaming experience? Is sustained play of 3D gaming a likely factor that will affect the transfer of preference for VR as a mode of cultural heritage learning? What about prior VR experience and use and how it affects the acceptability of VR as a mode for the learning of cultural heritage? The perception of reality in a virtual environment is important in its believability, and, as a consequence, the acceptability of VR as being a positive experience is crucial for the learning of cultural heritage. What are the factors affecting believability, a sense of presence and how personal meaning and experiences are formed? Our virtual environment was designed to answer these questions.

Fig. 1. Scenes from the virtual environments.

3.2 Virtual Reality Hardware and Software

Unreal Engine 4 was used as the preferred engine for our heritage virtual environment. Terrain, river systems, skybox, and atmospheric effects were created within Unreal Engine from which the 3D models (FBX with embedded textures) were placed. The 3D models were reconstructed within Blender, and textures were created from our texture image database in Photoshop and UV mapped in Blender. Photogrammetry reconstructed models use a combination of AutoDesk's ReCAP and RealityCapture with models decimated at around 70%.

Specifications of our VR system includes NVIDIA Quadro M6000 (24 GB), Intel i7 2.4-GHz 12-core CPU, and 64 GB of RAM. The HTC Vive and controllers were used with a realistic model of human hands for interaction and navigation. HTC Vive allows up to 5 × 5m of navigation space, and therefore the setup provides fluid movements within a highly realistic environment.

3.3 Site Reconstruction

The virtual environment hosts both photogrammetry and reconstructed 3D models. The mixture creates a highly realistic environment (see Figures 1 and 2). We reconstructed the *Sanjiangkou* Maritime Silk Road Port from ancient maps, terrain information, literary descriptions, photos and models provided by Ningbo Museum's curators, a collaboration partner in our project. The entire built area is a virtual landscape consisting of a space with the maximum size of 10,000m^2. Within the landscape, we constructed a section of the *Sanjiangkou* site at approximately 1,000m^2, a user-navigable area that allows users to freely roam using the HTC Vive's motion controller. The user-navigable area at the site uses Unreal Editor's Navigation Mesh and thus prevents users from going out of the boundary. Users can navigate by physically walking within the 2.5m × 2.5m space (Figure 3) tracked and mapped to movements in the virtual space. Longer-distance travel is facilitated by using the thumb and holding the trackpad (either left or right) and indicating where the user would like to be transported to. The release of the trackpad transports the user to the intended location.

Within the "walkable" area is a building, a Yuan Dynasty storehouse (Figure 1, top right), of size 4 × 8m, which the user can enter into by opening and closing the doors using the motion controller's Trigger button, and using the index fingers (either left or right). The storehouse contains an ornament rack decorated with jars and jugs, a seating area consisting of two chairs and a table, and a store area containing (箩筐 Luokuang), some ropes,

Fig. 2. A collection of objects positioned within the virtual environment.

wooden barrels and ceramic pots separated by a traditional foldable screen (屏风 Pingfeng). All items within the house are moveable and items on the shelves are objects reconstructed with museum artefacts as references. The external area immediately outside the storehouse is a cauldron on an open fire surrounded by vegetation and slabs. Photogrammetry objects such as entrance ornaments (门墩 Mendun), doorknobs and stones decorate the facade of the storehouse. Apart from the storehouse, users could also stand on the boats lining the shores (Figure 1, bottom right). The main structures of the ship is reconstructed from a model within Ningbo Museum, and the 3D mesh is edited and enhanced with more details.

On top of Yuan Dynasty artefacts, we captured heritage objects from other time periods from other sites and museums, and inserted them into the scene at their logically and culturally appropriate positions, such as the stone lion (see Figure 2, bottom left). Listed in the table below are objects within the "walkable" area of the site with indicators on whether they can be interacted with or broken (Table 1).

3.4 Experiments and Participants

This section elaborates on our laboratory settings, the procedures for recruitment, and the details of our experiment.

3.4.1 Laboratory Setup. The experiment was held at the NVIDIA Joint-Lab on Mixed Reality, enclosed within a 2.5 × 2.5m space (see Figure 3).

3.4.2 Participant Recruitment. We recruited a total of 61 Nottingham University students within the age group of 18 to 28 years old, via various social media. The student base of the University of Nottingham's China campus is represented by over 40 countries. We placed no restrictions and quota on our demographics, allowing diversity

Table 1. A List of Objects in Different Areas of the Virtual Environment

Items	Interactable	Breakable	Reconstructed	Photogrammetry or with Museum Object as Reference
Store Room				
Door knob with Qilin head	X			X
Ornament Rack	X		X	
Jars	X	X	X	X
Jugs	X	X	X	X
Bowls	X	X	X	X
Desk	X		X	
Chairs	X		X	
Vase Rack	X		X	
Luokuang	X		X	
Oranges	X		X	
Pingfeng			X	
Weapons Room				
Swords	X		X	
Spears	X		X	
Knives	X		X	
Open Area				
Mendun				X
Stone Lion				X
Ship			X	X
Boats			X	
Vegetation			X	
Stones			X	
Jugs	X	X	X	X
Pots	X	X	X	X
Cargo Containers	X		X	
Wooden Barrels	X		X	
Luokuang	X		X	
Oranges	X		X	
Camp Fire			X	
Cauldron	X		X	

as well as the natural build-up of demographics. Ethics approval was obtained from our university's Ethics Committee prior to our user study or data collection.

3.4.3 Experimental Procedures. At the start of the experiment, we explained the process and requested participants to complete a survey consisting of 11 background questions. The VR session begins with minimal guidance, allowing users to explore in varied durations depending on participant comfort (from 3 to 20 minutes). The session ended with further questionnaires.

3.5 Quantitative and Qualitative Questionnaires

We created 70 questions, combining both 7-Likert scale questions and open-ended questions, with some questions adopted from other established questionnaires. They are too numerous to list here but the findings section does reveal details of our questionnaire. Nine areas define the nature of our questions:

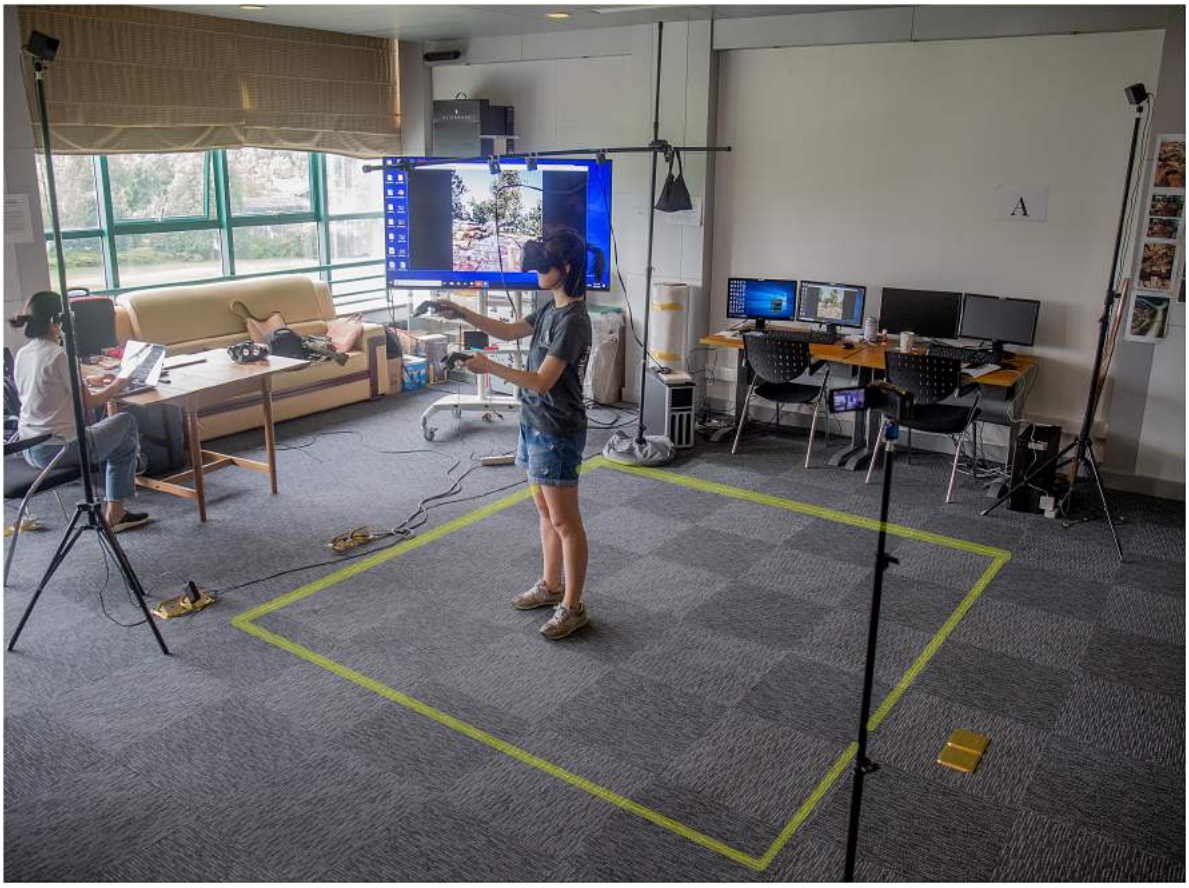

Fig. 3. The VR space used in our experiment (2.5 × 2.5m).

Demographics Data - consisting of demographics data age, gender, level of education, and so on.

Prior Experience - five questions on participant knowledge where participants recalled memories on VR, 3D gaming, history of ancient Ningbo, Yuan Dynasty.

Personal Preference - consisting of 8 questions on preferred methods for obtaining cultural heritage-related knowledge, preferred duration of each VR session, as well as their preference of having multiuser VR environment.

Expectations - consisting of nine questions collecting participants' expectations of new experiences to be gained prior to the VR session, and observations after the VR session, expectations of the use of VR in museums, and suggested improvements.

The Sense of Presence - consisting of five questions adapted from the Presence Questionnaire [45], collecting participants' sense of "being there", sense of activities, and sense of actually visiting the site.

Exploration and Navigation - consisting of nine questions that collect participants' interaction and impression in the environment. This is where participants makes sense of, and get familiarised with the virtual environment by exploring and experiencing the heritage site.

Curiosity and Interests - consisting of seven questions collecting participant interests in the use of VR and their preferred approaches to learning cultural heritage.

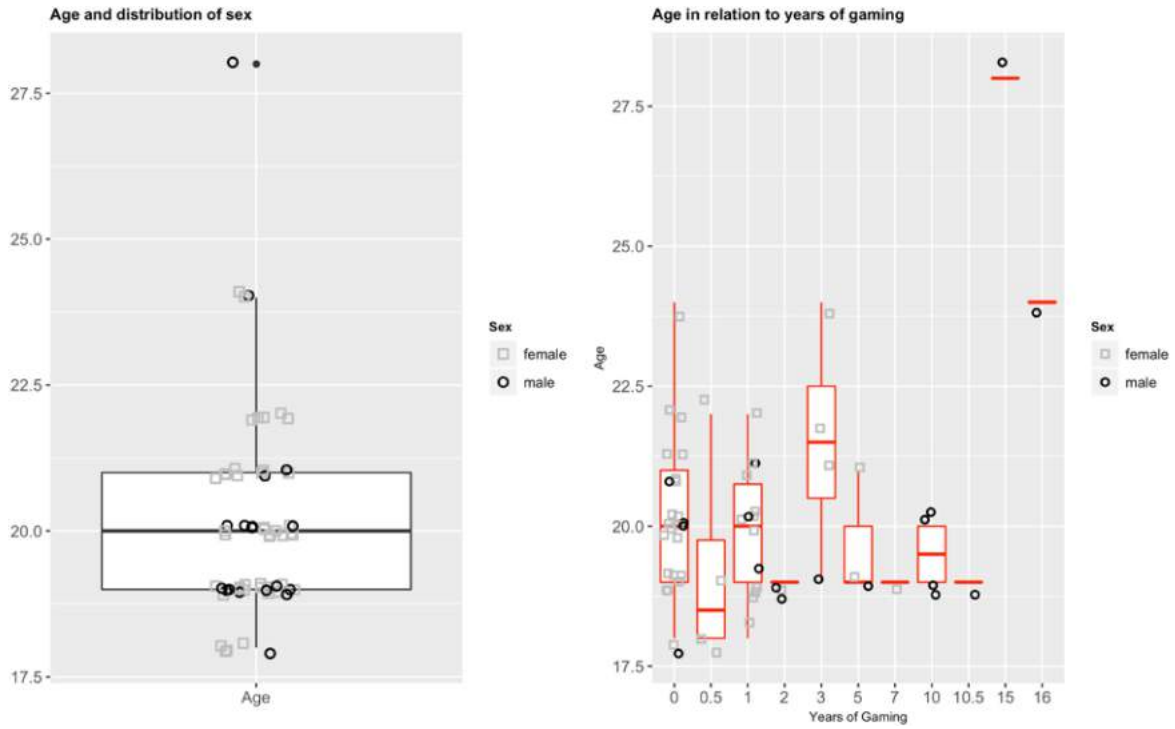

Fig. 4. Distribution of participant age and gender and their relation to years of gaming.

The Conceptualisation of Ideas - consisting of seven questions collecting conceptualised ideas where participants make connections by interacting with the objects, define new meanings from the interactions, and identify new characteristics, and refined their perception of the environment.

Results and Decisions - consisting of 16 questions collating personal evaluation of concepts or ideas where participants present the corrections needed, comparisons, new discoveries, and potential opportunities that should be addressed in the future.

4 FINDINGS

Here we report on our findings, mapping demographics, background, the preferred mode of learning, prior experience of VR to acceptance, experience, and expectations.

4.1 Age and Gaming Experience

We analysed the distribution of participant age in our study, looking at the balance of gender and how the age and gender of the participants are distributed around their years of gaming experience. There were a total of 61 participants, 43 in the female group and 18 in the male group (Figure 4). The gender distribution is approximately equivalent to the ratio of the university at 7:3 (female:male). However, our analysis shows that gender has no significant effects on the use of VR. The mean for our participant age is $\mu = 20.15$ and the standard deviation is $\sigma = 1.74$. The youngest is 18, and the oldest is 28.

When we look at participant age in relation to years of gaming, we see that they were clustered around 0 to 1 year. Forty percent ($n = 25$) of our participants have no gaming experience, 22.9% ($n = 14$) have 1 year of gaming experience, 30% ($n = 18$) have more than 1 year of experience, and the remainder have just started playing 3D

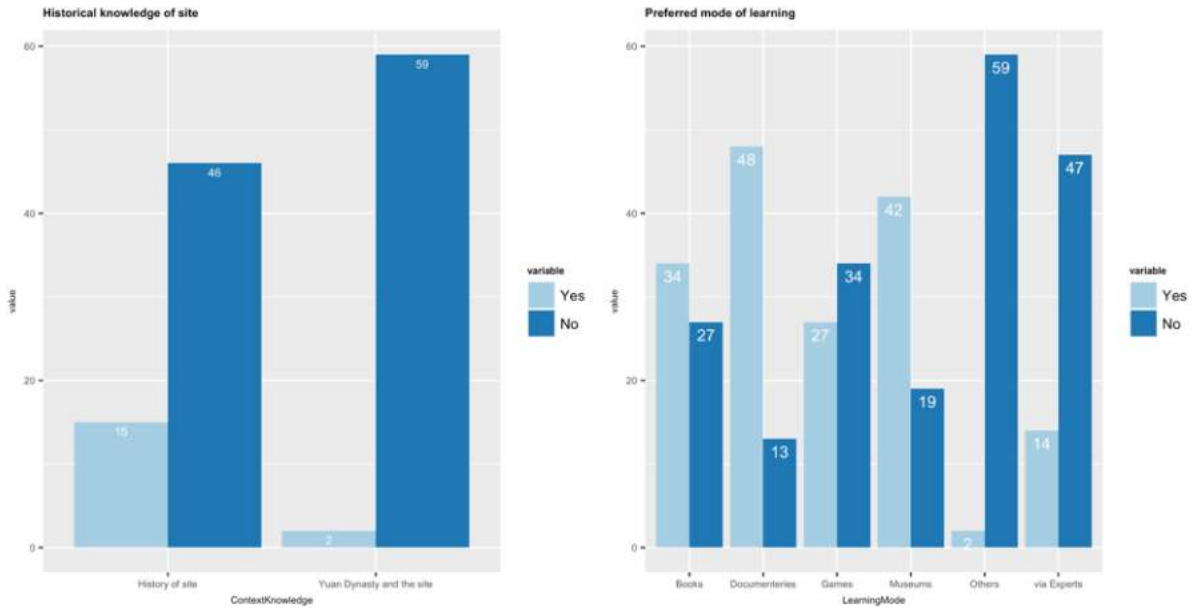

Fig. 5. Indicators of participant knowledge of the context of our VR environment and participant preferred mode of learning.

games. We hypothesised that 3D Gaming experience is important in the familiarity with VR. Apart from total immersion in a 3D environment, 3D gaming does contribute to the familiarity of participants in interacting with and navigating a virtual world.

4.2 Knowledge of the Virtual Heritage Site and Preferred Mode of Learning

Depicted in Figure 5 are indicators that our participants had little knowledge of the history of the *Sanjiangkou* site, and how the Yuan Dynasty is related to it.

The second graph indicated the preferred mode of learning for cultural heritage. Most participants preferred watching heritage documentaries ($n = 48$), followed by visiting museums ($n = 42$), reading books ($n = 34$), and playing games ($n = 27$). Very few preferred talking to experts ($n = 14$), and through other modes of learning that involve more interactions. Despite the fact that heritage documentaries and visiting museums are known to be prevalent approaches for obtaining historical knowledge, in our observation, we saw that most participants who have signed up to our VR experiment preferred visually oriented learning modes—these are documentaries, books, and games, all of which relate to learning through the visual modality. We observed, therefore, that users who have shown interest in VR and have signed up for experiments tended to prefer a more visual approach to learning.

4.3 Prior Experience of Virtual Reality

Our set of participants was balanced in terms of their prior experience with VR in different devices (Figure 6). Desktop VR was the majority at 34% ($n = 21$), followed by access to smartphones 30% ($n = 18$) and Tablet devices 23% ($n = 14$). Other devices were through the use of consoles such as Sony PlayStation, and and so on.

4.4 Experience and Meaning Induced via Virtual Reality

Does prior gaming or the use and the experience of VR affect the acceptability of VR for the experiential learning of cultural heritage (RQ1)? The first graph in Figure 7 indicated that gaming experience negatively correlates with

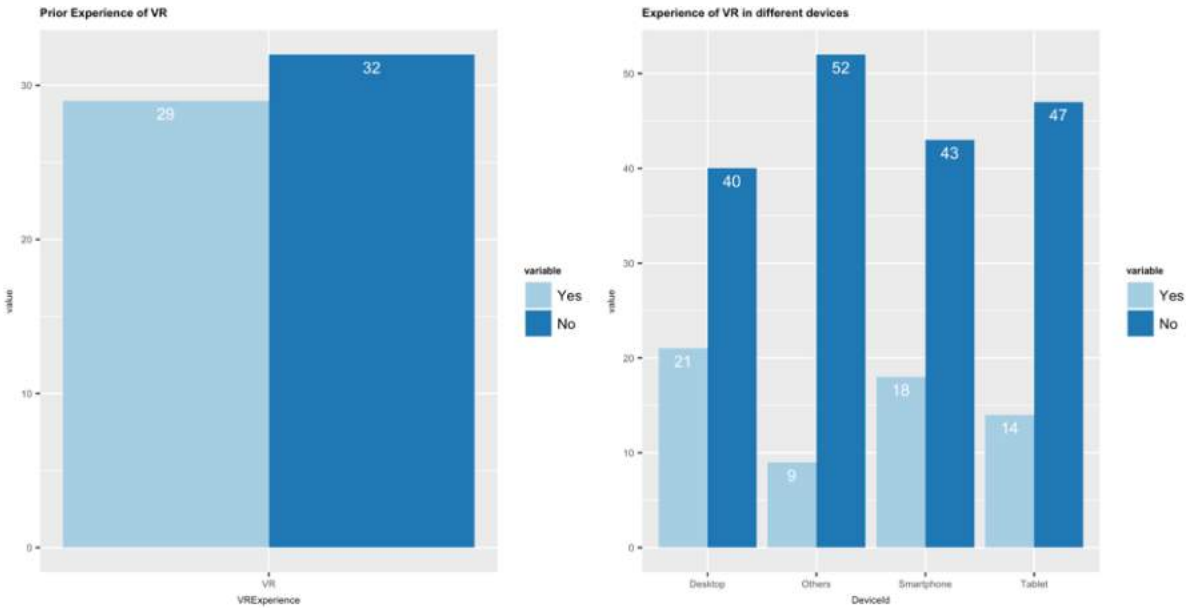

Fig. 6. Prior experience of VR and in different devices.

a sense of being there at the site ($p < 0.05$). With the majority of participants having little experience with 3D virtual worlds, the majority of participants with 0 to 3 years of experience reported a higher sense of being there. 3D gamers with over five years of experience generally reported a lower sense of being there. This may be due to expectations from professional-quality graphics in the prior gaming experience, which our small team may not have the resources for. Box-office games are designed with hundreds of developers in the production pipeline.

In the second and third graphs, we see that ease of navigation positively correlates ($p < 0.05$) with a sense of being at the site. Ease of navigation negatively correlates with the perceived length of time it took for participants to familiarise themselves with the environment. Users were able to focus on exploring the site and gaining information as a result of the ease of navigation. Some users explored walking on both tiles and grass and oriented their gaze between sunlight and shade. They also tested interactable objects.

Does the believability of virtual environments and objects provide a means from which meanings and memories may be formed (RQ2)? Participants whose activities, i.e., "the things I did," were thought to be meaningful to them had a stronger sense of being at the site (bottom left, $p < 0.001$). Similarly, an additional question cross-examining the sense of being there indicated significant correlations (bottom centre, $p < 0.001$). Participants felt that there was a real sense of being at the site, a strong sense of presence, and a feeling of being transported to the actual site. These correlated with the activities they did, which was felt to be personally meaningful to them. Participants who reported a stronger sense of meaningfulness in the activities correlated with the perception that the objects they have interacted with have meanings, histories, and individual characteristics. This suggested that activities around objects are an important component of the believability of a virtual environment for cultural heritage.

Do user curiosity and exploratory behaviour influence their experience of virtual environments (RQ3)? Figure 8 is a set of graphs mapping the relationships between the freedom of exploration, curiosity with objects, and familiarity with the sense of presence and meaning. Our study shows that the personal freedom to explore or rearrange the objects (top left), such as bringing the home furniture to an outdoor space, is negatively correlated ($p < 0.01$) with having a strong sense of reality. This may suggest that since users were able to freely

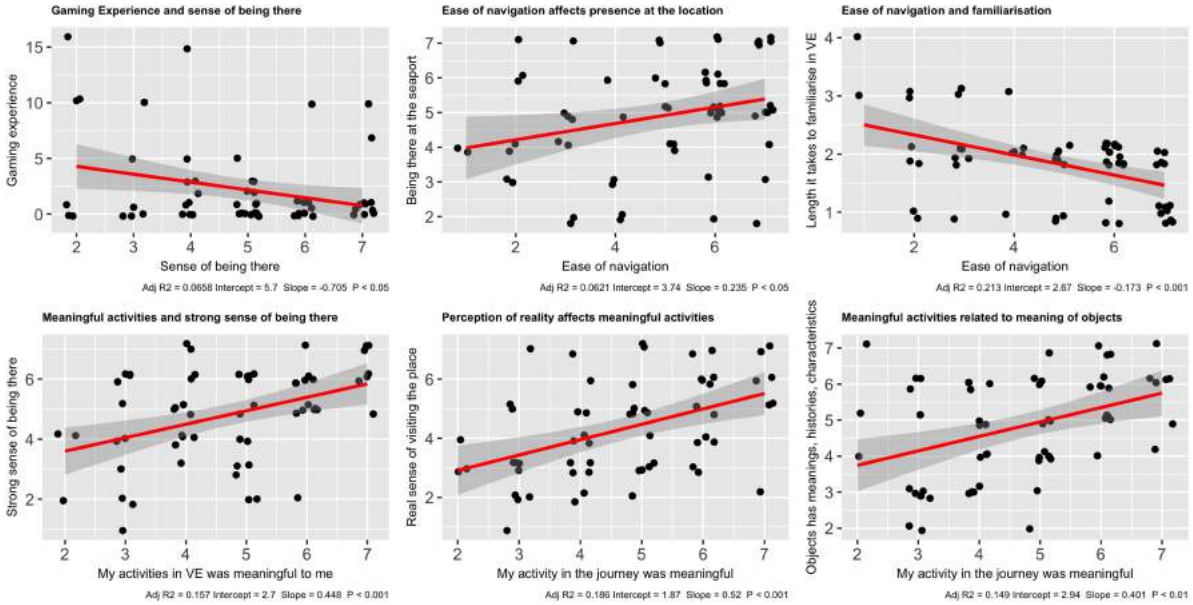

Fig. 7. The relationship between the sense of being there, ease of navigation, and perceived meaningfulness of activities.

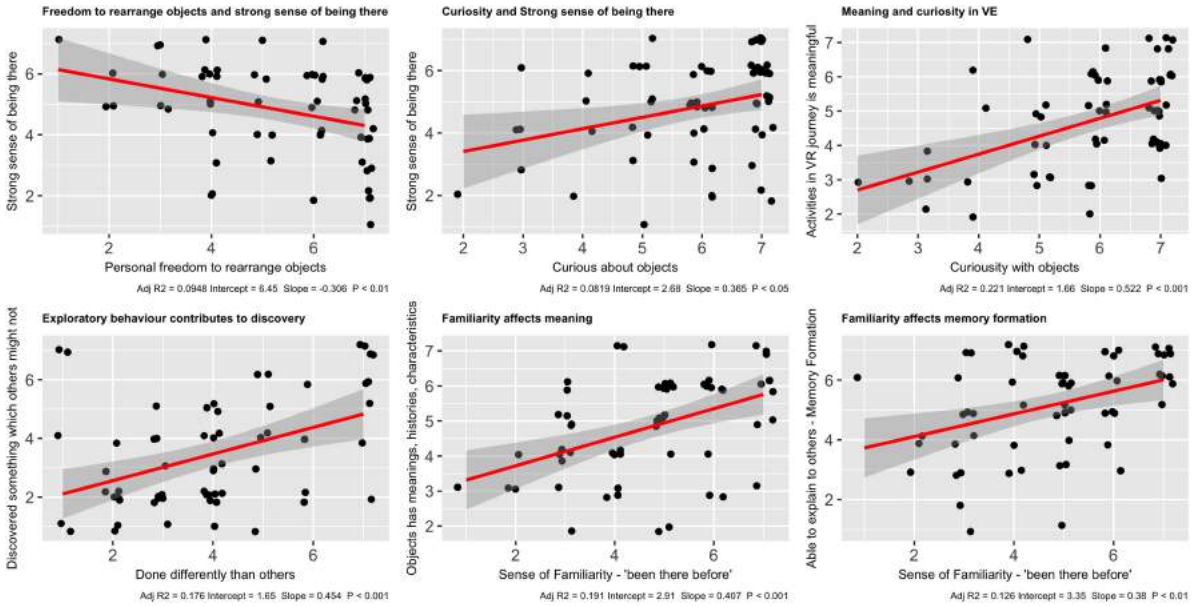

Fig. 8. The relationship between freedom of exploration, curiosity with objects, and sense of familiarity with the sense of being there and meaning.

rearrange objects, the world in which they were at the time could not be real, for river conjunctions where trade occurs and where security is tight must have certain formalities. Unsupported affordances—objects not being interactable—is a negative factor. Users discovered that certain activities were not expected from the real world, i.e., climbing a tree, igniting a bamboo basket or roasting the orange with the fire, and that virtual objects have no weight. These factors do reduce the sense of presence.

Users with high curiosity with objects reported a stronger sense of presence (top centre, $p < 0.05$) and stronger sense of the meaningfulness of their activities (top right, $p < 0.001$); these together with the graphs in Figure 7 suggested that activities and the ability to interact with objects digitised with photogrammetry from actual cultural heritage collections are important in virtual reality experiences.

Exploratory behaviour contributes to the perception of discovery. Users who reported the belief that they had done differently than others reported that they had discovered something about the site that others might not have (bottom left, $p < 0.001$). Users' responses showed that those who were more exploratory were more creative in their interactions with objects—using a porcelain vase fragment they broke for cutting oranges, squeezing an orange, stacking containers, and throwing items into the sea.

Users who reported a stronger sense of familiarity with the site believed that the objects are meaningful and have histories and characteristics (bottom centre, $p < 0.001$). Users related what they saw in the environment with their own memories, such as the games they have played, the dramas they watched, and the experience they had in the museums. This nostalgic effect does help build a connection between the digital objects and their personal experience, which in turn, contributes to their perception and interpretations of the objects. The realism of VR was a factor. In addition, users expressed great respect for history and acknowledged the meanings embedded within the virtual relics, which they were able to closely inspect, and the virtual means to travel back to the past.

The same group of users reporting a higher sense of familiarity felt that they were able to later, explain to others about their experiences in the ancient site (bottom right, $p < 0.01$). We found that when users describe their experiences, they tended to refer to the objects they were most familiar with, especially when they have had prior memories of the objects. This enriched and reinforces their experience in the virtual environment. When users were excitable by having their memories recalled, they reported the willingness to share and describe their new experiences and feelings to others. They also reported that they would rather have their friends experience VR than having to explain it to them. This indicated new potentials for attracting participants to museums via word of mouth.

The analysis above suggests the formation of memories whilst users were in the virtual environment. Our virtual environment both triggered memories and contributed to the retention of memory. This is a simple attempt to understand how a virtual environment contextualised with ancient cultural heritage can trigger memory, i.e., potentially effects of nostalgia, and the retention of memory that can later be communicated. A deeper study on the relationship between nostalgia, memories and VR has been conducted [5].

4.5 Prior Knowledge, Modifying the Site, and Detection of Irregularity

Is prior knowledge a factor that influences the ability of users to detect irregularities (RQ4)? We asked two questions to explore prior knowledge of the historical site (Figure 5, left) and the ability of users to detect irregularities and, as a result, make changes to the virtual environment. The detection of irregularities shows that care should be taken when attempting to design accurate historical representations.

The questions were "Q36. I modified and rearranged the objects because they are not accurate according to what I know about the history of the Chinese culture." and "Q37. I noticed that not all objects belonged to the same historical period."

The mean for Q36 was $\mu = 2.67$ ($\sigma = 1.56$). Those who had prior knowledge ($\mu = 3.5$, variability cv = 50) were more likely to modify the environment than those without ($\mu = 2.39$, variability cv = 58.13). For those who

Table 2. Questions on User Acceptance, Expectations, and Learning Preference

#	Questions	Mean	SD
Q49	I have learned something new about the *Sanjiangkou* from this VR journey.	2.98	1.54
Q51	I met my expectations through this experience.	3.98	1.53
Q53	I prefer this way of learning (with a VR journey) for getting to know more about cultural heritage.	4.98	1.69
Q55	I think that this kind of VR is suitable for learning about histories in museums.	5.98	1.69
Q57	I expect that museums in the future will use VR.	6.00	1.28
Q59	I think that this VR journey can be improved. There is something else that I can suggest for this environment.	5.67	1.29
Q61	This VR journey has motivated me to find a different way to learn about cultural heritage.	5.30	1.48
Q63	I think that VR can create more interest to learn about cultural heritage.	5.44	1.50
Q67	I think that it will be helpful if I can "travel" together with other people in this VR journey using multiuser VR.	5.69	1.35

noticed that not all objects belonged to the same historical period (Q37), the mean was $\mu = 3.4$ ($\sigma = 1.72$). The sample size was too small to gauge the variability between those with knowledge and those without.

Based on the qualitative feedback, most users did not observe irregularities nor assumed that the information we provided was incorrect. Nevertheless, some correctly pointed out the irregularities based on their general knowledge of history, e.g., the house and the stone lion do not belong to the same historical period and that the trees in the backyard are not native species.

4.6 Acceptance, Expectations, and Learning

This section concludes the main question (RQ0) with data from our findings in the previous section. We initially asked if there will be effects on the acceptance, experience, and expectations of cultural heritage learning mediated via virtual environments. We have shown that those who reported more years of gaming experience also reported a lower level of the sense of presence, while this may be the case, those who reported more years of gaming experience also preferred VR as a means for the experiential learning of cultural heritage (Figure 9, top left, $p < 0.05$). When we gauge our participants on how acceptable the time assigned in the virtual environment was, i.e., "the time assigned for me in the virtual environment was too short," in a scale of 1 to 7 (7 = strongly agree), participants reported a mean of $\mu = 3.74$ ($\sigma = 1.797$). There was a good distribution of those with prior VR experience and those without. The coefficients of variation for "Time assigned was too short" for those who have prior experience of VR was cv = 43.965, and those without were cv = 48.996. Whilst there was a slightly higher variation of non-VR users reporting that the time was too short. The variation was not significantly greater. This indicated that there was no significant variation between those who have prior VR experience and those without. The time assigned was acceptable for all kinds of users, but first-time users generally preferred more time. We further tested the coefficient of variation on those with gaming experience and those without and discovered a similar trend. The coefficient of variation for those with gaming experience was cv = 50.96 as compared to those without cv = 45.39.

We observed that those who had more years of gaming experience picked up the controller methods for navigation and interaction more quickly. Therefore, less time was spent familiarising themselves with the technology, which resulted in more time spent on the experience itself. They reflected that "for me it was sufficient. I finished exploring very quickly, perhaps it's because I am used to VR." However, those who were new to VR tended to spend more time on familiarising themselves with the controllers. The teleporting feature for navigation differs from users' mental models on walking as it prompted the users to jump to another location directly [40]. Some users felt slight motion sickness when teleporting. Hence, the comments "I think I will have more fun if I can play longer, but I felt a bit dizzy." The design of future VR contents should take note of the findings here.

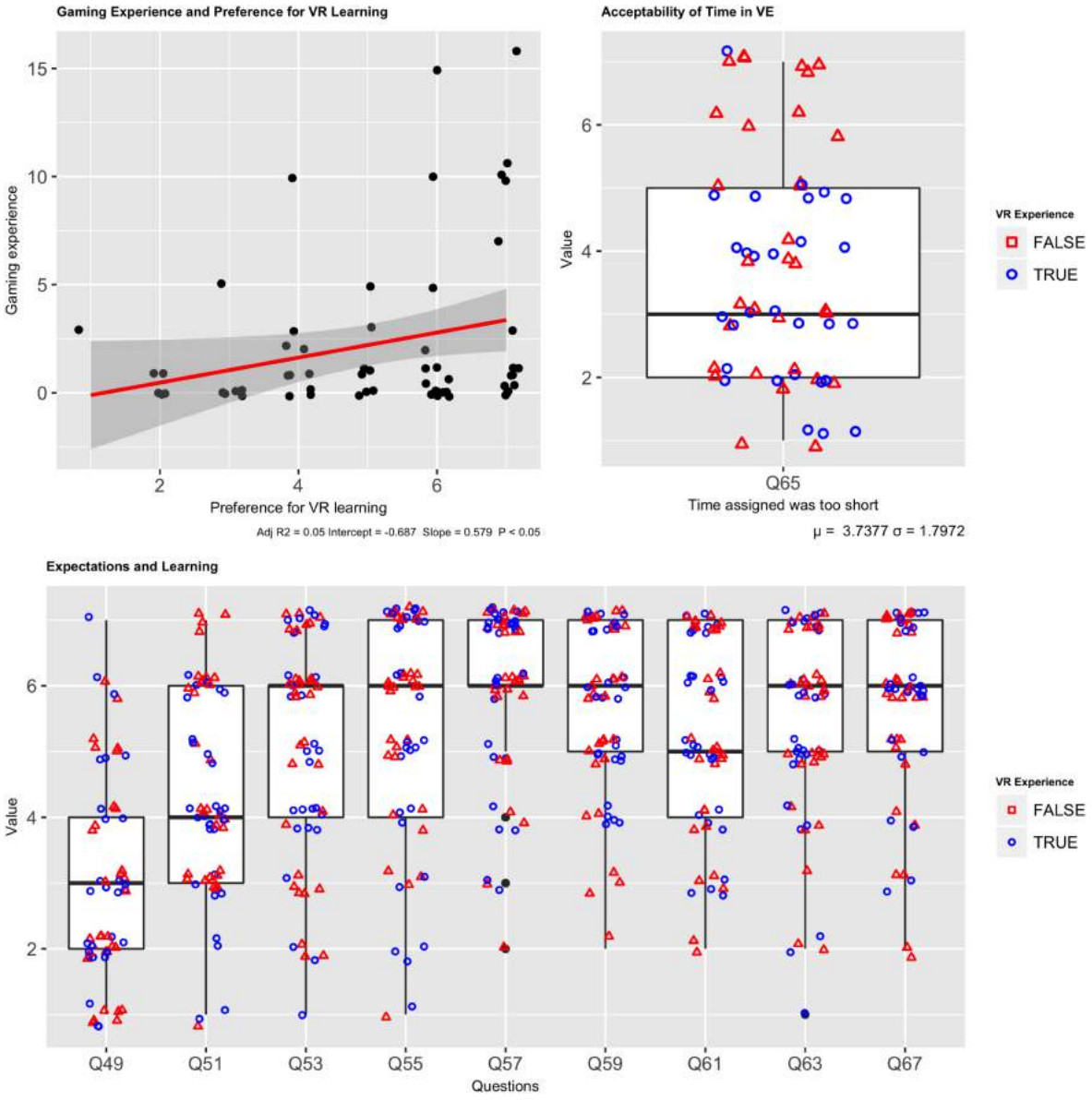

Fig. 9. Prior gaming and VR acceptance, experience and expectations.

In terms of expectations and learning, those with and without prior VR experience were roughly similar (Figure 9, bottom graph). Each boxplot relates to a question asked of participants, with a Likert scale of 1 to 7 (*strongly agree*).

Q49 reported a mean of 2.98, showing that users did not actually learn anything new about the ancient site. This is expected as the site we created was exploratory and not pedagogical. However, users reported that they enjoyed the experience, saw the structure of the merchant ship, the layout of the site, and commented that the defensive wall should be this close to the river and the ships were not tied to the docks. They also questioned

the lack of particular aspects of a port: "[there were] no aquatic food merchants around the river" and "I could have learned more if I can board the ship."

The virtual environment met our participants' expectations (Q51, mean = 3.98) for the VR journey. From Q53 to Q67 (average mean of $\mu = 5.58$), the report was very positive, indicating a strong acceptance of, preference for, and expectations of VR as an environment for learning cultural heritage. In Q59, users reported that they had suggestions for improvements.

Users expected the affordance of object to be at least similar to the real world [52], e.g., seeing a ship provided expectations that they can be boarded and sailed, and that tree leaves should be affected by the wind, and so on. This informed us that the design of virtual environments should provide affordances expected from reality. Users also suggested the inclusion of historical texts, images, and audios around artefacts, which can explain their use and contexts. Users also reported the need to engage with other people and/or AI. This related closely with the positive responses in Q67, where users agreed to the idea that experiencing virtual heritage together with another person is important, i.e., shared experiences with friends and families. Sharing and exploring together can contribute to learning experiences. The design of purposeful activities and the inclusion of other users could prevent users from "wandering around for no reason." It may also reduce the sense of fear of being alone in a virtual world. Several users expressed interests in having historians and domain experts accompanying them in the virtual visit, showing a preference for an embodied approach of gaining information in the virtual environment [37].

When users were not told the purpose of the virtual environment, they proactively asked for information when they were exploring the virtual environment. Overall, all participants demonstrated a high rate of acceptance for VR as a learning tool for future museums.

Overall, users reported positivity of the future use of VR in museums: "VR can depict history in an interactive way and allows me to better imagine history" and "the immersive experience of VR experience can raise my interests for learning history as compared to reading literature and watching documentaries." This concludes our findings. Our study demonstrated that virtual environments do have an effect on user acceptance, experience and expectations for VR as a learning tool for cultural heritage.

5 DISCUSSIONS

In this article, we investigated how well cultural heritage mediated via Virtual Reality environments is agreeable and acceptable to those who are within the category of the "younger" generation. We investigated how reconstructed heritage sites and objects stimulated experience and gauge user expectations when VR is used for communicating cultural heritage. Whilst there are aspects of learning involved in our study, our focus is on the acceptability, experience, and future expectations related to the experiential learning of cultural heritage. The study investigated how participants accept and are stimulated in terms of personal experience, and their expectations and ideas for the future of museums if VR is used for enhancing the learning of cultural heritage.

There were a total of 61 participants, 43 in the female group and 18 in the male group (Figure 4). We were not able to explain why the study attracted more females than males; however, our analysis shows that gender has no significant effects. The mean for our participant age is $\mu = 20.15$ and the standard deviation is $\sigma = 1.74$. The youngest is 18, and the oldest is 28.

It is important to note that at a time when there is a disparity between the East and the West in the participation of the "younger" generation in cultural heritage, that such challenges should be carefully addressed, and that emerging digital technologies should be investigated with regards to its use and how it can capture "younger" audiences. Close to half of our participants have prior experience of VR between devices, and the majority of them have 0 to 1 year of gaming experience. While we cannot yet have a solid conclusion, we observed that the preferred mode of learning cultural heritage for the majority of our participants were inclined toward a visually oriented learning styles, i.e., learning via watching documentaries, reading books and playing games. This data

is not surprising considering that we live in a media-rich environment pervaded by screens of various sizes. We will expand this initial information in the subsequent paragraphs to reveal our findings.

Does prior gaming or the use and the experience of VR affect the acceptability of VR for the experiential learning of cultural heritage (RQ1)? The answer is no. Our study demonstrated that VR is acceptable for the learning and experience of cultural heritage for both male and female users between 18 and 28 years of age. Those who reported 0 to *n* years of gaming experience reported that they preferred VR as a mode for the experiential learning and experience of cultural heritage, even though participants with more years of gaming experience reported a lower sense of "being there" due to factors described in our analysis. Neither does prior VR experience affect their preference for VR, although non-VR users tended to spend a longer time within the virtual environment. We also see that gender is not a factor.

Whilst VR is acceptable as a mode of learning, prior gaming and VR experience do affect the experience. We observed that the ease of learning of navigating a virtual world and interaction occurs in users who have prior VR experience and for users with more years of gaming experience. However, prior experience influences the time it takes for users to familiarise themselves with the technology and the time needed to experience the virtual environment. In a museum environment with high visitor numbers, the design of virtual environments needs to take this into account as VR technology is rivalrous and excludable. This also presents the need to develop multiuser VR environment, as reported by our participants stating the need to "learn together" and "share the experience of cultural heritage."

Does the believability of virtual environments and objects provide a means from which meanings and memories may be formed (RQ2)? We define believability as a subjective perception of what the virtual environment can provide in terms of its visual realism as well as the sense of presence. In other words, how does experience occur within a virtually reconstructed heritage site? Our finding suggested that activities around objects, which also contributed to the sense of presence at the virtual location is a key factor. The believability, i.e., the realism of the reconstructed heritage site and presence are both important and complementary factors, and photogrammetry techniques and present advances in VR have largely resolved the issue. Participants reporting a stronger sense of meaningfulness in the activities correlated with the perception that the objects they have interacted with have meanings, histories, and individual characteristics. This suggests that activities around objects are an important component of the believability of a virtual environment for cultural heritage. The freedom to explore the scene and interact with objects is important in the design of virtual heritage environments. However, balance is needed as we found that users who were freely rearranging objects had a lower sense of believability, as the site was likely to be formal spaces with stricter governance. It all depended on the context and therefore, care in design is important. Similarly, affordances are important in the believability of a virtual heritage site, which can contribute to better user expectations. Thus, cultural heritage mediated by VR is powerful as the believability of a site contributes to the formation of meanings and memories.

Familiarity influenced by prior encounters with objects in the real world, the usability of VR technology and a sense of believability contributes to the conception of meanings, and the perception that objects have embedded meanings. These factors are important in bridging a personal connection between users, objects and place. A sense of familiarity as an experience of place contributes to the formation of relatable memories within the virtual site. We conclude that the perception of reality is important in the experience of a virtual heritage site, and consequently, the acceptability of VR being a positive experience is crucial for the learning of cultural heritage. A strong sense of presence and believability is the first step towards positive VR experiences, and we have achieved that using accessible and affordable VR. Additional activities, personal meanings as a result of activities and the perception of objects as having meanings, histories and individual characteristics are important for VR adoption in museums.

Do user curiosity and exploratory behaviour influence their experience of virtual environments (RQ3)? Curiosity is an important factor for learning, especially when there is the need to navigate spaces and interact with objects within a virtual environment. By providing users with an unguided environment from which to inves-

tigate, exploratory users will attempt to test object and environment affordances [36]. If a virtual environment is not designed well, then the mental model of users of the real world when applied to the virtual world will reduce the sense of believability. Exploratory behaviour however, does contributes to a sense of discovery in our users. This is an important factor for influencing learning. However, user curiosity does contribute to the sense of believability and as a consequence, a sense of meaningfulness when some activities were carried out.

Is prior knowledge a factor that influences the ability of VR users to detect irregularities in a virtual heritage site (RQ4)? Visitors visit museums with different levels of knowledge. This independent variable is difficult to control when designing a virtual heritage site. We found that users who had prior historical knowledge of sites will detect irregularities whilst others will not. Virtual heritage sites, which have not been reconstructed accurately, will negatively affect learning and the sharing of information. The impact of learning is great.

Aside from the questions that we have asked and answered, we have also discovered additional information that could assist in the design of virtual heritage environments. We found that users who are interested in VR prefer a more visual mode of learning. While this is not a conclusive evidence as we have not tested the hypothesis, our initial observation suggests this to be the case. However, we believe that VR can facilitate this category of learners. A visual mode of learning involves the use of high-quality visual media and a reasonable sense of space to form a visual journey that can help users in recording contents within their memories and as such, visualise concepts in their learning process. A constructive learning approach applied within an immersive virtual environment can possibly facilitate the construction and imagination of the scenes of historical places in their minds. Hence, we believe that visualised concepts can support the experiential learning of cultural heritage for visually oriented learning styles. Our future research will expand upon such a concept.

Present VR technology contrasts with traditional media, such as texts, images and videos by offering users a virtual journey using their entire physical bodies. This creates a phenomenology of place. The sense of embodiment in VR [32] can afford the embodied experience of "being there" in the historical context. The ability to pick up objects, interact with them and inspect them at close range in the context and environment of their historical period has great potentials for experiential learning. In this sense, artefacts in museums become alive with meaning and characteristics in relation to their contexts, for they were not encased within glass displays as a museum exhibit. Freedom of exploration is a characteristic of virtual worlds. It allows users the freedom to navigate and explore a landscape and the objects within. This is an important component of virtual worlds, they can be unguided or designed as a guided tour, e.g., as a narrative, directing users to important locations. However, we think that, based on our data, too much freedom can be detrimental to learning.

VR is a powerful medium for communicating cultural heritage. In summary, our study does not attempt to resolve the dwindling interests in museum participation. Rather, our concerns lie in the need to generate interests and equally the need for effective learning of cultural heritage. We are directed by our goal to attempt to understand and to create more engaging experiences, using the constructivist learning theory, for bringing cultural heritage to the younger audiences through a more effective, visually stimulating and meaningful approach. Our studies have shown that users become interested in using VR for the experience of cultural heritage not because of the "coolness" of the technology, but because of the experience the medium can afford. We believe that experiential learning can occur when users acquire knowledge through embodied experience of reconstructed heritage sites using VR technology.

ACKNOWLEDGMENTS

Special thanks to Ningbo Museum for their contribution and expertise in the history of the *Sanjiangkou* site.

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Received October 2018; revised April 2019; accepted July 2019