# Chapter 23
# A Framework for Sharing Cultural Heritage Objects in Hybrid Virtual and Augmented Reality Environments


**Yue Li and Eugene Ch'ng**

**Abstract** The emulation of social environments within which ideas, knowledge and interpretation are exchanged is a challenge for Extended Reality (XR) technologies. One aspect of the challenge is the concept of Extended Reality itself, and this within the broad spectrum of the physical and virtual reality continuum. As users settle down into the spectrum via their preferred devices, so must we investigate the viability of communication between users adopting different modes of XR. In this chapter, we discuss three attributes of virtual objects and explore the concept of a Hybrid Virtual and Augmented Reality (HVAR) environment. We look at how users from different realities could interact, engage and communicate in a shared space via objects. We believe that the use of HVAR environments is the way forward for connecting worlds, and that it will facilitate future communications around virtual objects, developing and flourishing across time, space and devices, much like how social media has facilitated user-generated contents, empowering individual interpretations and the formation of collective meanings. The concept of a hybrid space aims to gather communities from disparate backgrounds and cultures, and to facilitate discussions around objects of interest.

**Keywords** Extended reality · Virtual reality · Augmented reality · Digital heritage · Virtual heritage

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## 23.1 Introduction

Prior research in Digital Heritage has seen the use of both Virtual Reality (VR) and Augmented Reality (AR) in museums, for immersive visualisation and the augmentation of virtual objects in physical spaces. These reality technologies were primarily configured for use within museums, often as an enhancement to the relics as displays are not physically accessible to visitors. Recent advances in the usability and affordability of Extended Reality (XR) technologies are also providing new opportunities for cultural heritage to be accessed outside the walls of cultural institutions (Bekele et al. 2018). However, virtual and physical objects have significant differences and it remains a challenge for XR to emulate the physical, material and social aspects of an actual museum visit. In resolving the issues, the diversity of devices preferred by users should be a factor taken into the account of designing for large audiences, this being one of the central and core ideas of visitor centricity that we believe in, in the design of XR systems. In addressing such a need, we explore the ability for users to socialise between reality technologies, by constructing an environment that can facilitate the connection of people from different worlds—a Hybrid Virtual Augmented Reality (HVAR) environment (Fig. 23.1).

VR experience is 'any in which the user is effectively immersed in a responsive virtual world' (Brooks 1999). However, AR does not replace the real world with

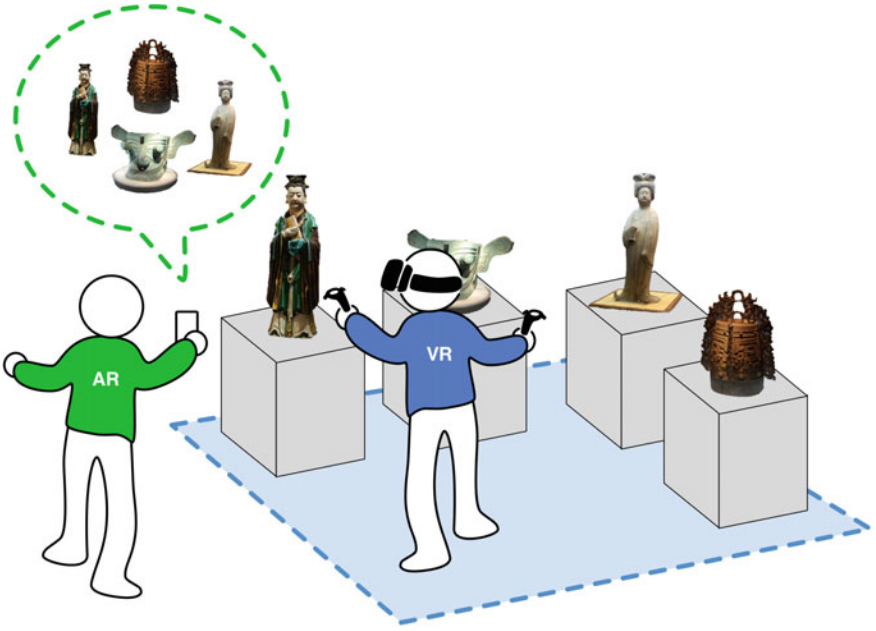


**Fig. 23.1** A scenario of use in the hybrid virtual and augmented reality environment (Y. Li and E. Ch'ng)

an entirely simulated environment as VR does, but it instead combines the real and virtual to supplement the physical world with augmented objects (Azuma 1997). Both VR and AR register objects in 3D and support real-time interactions. We observed three significant trends in present VR and AR technologies. First, VR and AR have become increasingly accessible to individual users. Two decades ago, VR and AR were primarily used in institutions, organisations and research laboratories for specific visualisation research and training purposes. We have progressed to witness an increasing number of consumer-level VR and AR devices in the market that range from desktop VR Head-Mounted Displays (HMDs) to smartphones that support both VR and AR. Corporate investments and recent demands have brought VR and AR technologies to the general public and making them increasingly accessible to individual users for more general purposes, including entertainment, education, social networking, e-commerce and marketing (Cipresso et al. 2018).

Second, a growing variety of VR and AR devices will likely be supporting social interactions. When Facebook acquired Oculus in 2014, Facebook CEO Mark Zuckerberg (2014) envisioned that 'one day, this kind of immersive, augmented reality will become a part of daily life for billions of people'. VR and AR are expected to be used for social networking with mass-market adoption. Although we have yet to see such a prediction come true, industries are working towards it. Recent updates have demonstrated their potential use in the social context. For example, Oculus and Valve have both launched wireless standalone VR devices with 'inside-out tracking', such as the HTC Vive Focus (VIVE Enterprise 2018) and the Oculus Quest (Facebook 2019). This recent trend is enabling VR devices to be used in more practical scenarios and is very likely to become regularly used for sociality. Recent applications such as VRChat (VRChat Inc. 2017), AltspaceVR (Microsoft 2018) and Avatar Chat (Magic Leap 2018) have also demonstrated the potentials of VR and AR for enabling social interactions, such as personalised 3D avatars, selfies and multi-viewer 360-degree videos that replicates a cinema audience. As users adopt preferred devices between the XR spectrum, we think that it is essential to investigate social interactions that can be facilitated at the intersection of devices and across the XR spectrum.

Third, there is the merging of the real and virtual. We predict that hybridity in reality technologies will be a future trend. Speicher et al. (2019) interviewed domain experts in VR and AR as a part of their survey of XR research. Results from the interview suggest that the distinctions between AR, Mixed Reality (MR) and VR are diminishing and will continue in the trend in the coming 5–10 years. Users are likely to internalise the differences as they are exposed to more of such technologies. Researchers have also introduced ideas and frameworks of hybrid realities, such as the One Reality framework (Roo and Hachet 2017) presenting six levels of realities that incrementally bring the physical world into the virtual. VR and AR are essentially 3D interfaces that are capable of presenting information with common modalities—text, audio, video, 3D models and so on. Depending on the use case scenarios, situated environments, subjective preferences and available devices, users may opt for augmented visualisation, immersive VR experience, or a transition between the two. The line between the real and virtual is increasingly blurring and thus, hybridity in reality technologies will become a future trend.

VR and AR technologies have become accessible and affordable with a growing variety of XR devices in the consumer market. As users adopt preferred devices used for XR, the need to support open and connected social experiences become mandatory research with very practical future outcomes. In the following section, we demonstrate how virtual objects can be used as an interface between VR and AR for connecting hybrid environments. We present the Visualisation, Interaction and Presentation (VIP) Framework of Virtual Objects and the Contextual Experience Cycle of Virtual Exhibitions. We then present a design of HVAR system applying the VIP Framework of virtual objects, supported by a qualitative analysis that evaluates multiuser interactions using the Contextual Experience Cycle of Virtual Exhibitions. The theoretical contribution provides a practical foundation for the application of VR and AR both in contemporary thinking, and in the future of digital cultural heritage.

## 23.2 Virtual Objects—Connecting the Virtual and the Real Environments

Champion and Dave (2007) classified virtual heritage environments into three types: visualisation-based, activity-based and hermeneutic environment. The first and most common type concerns the visualisation of objects and environments in a static and immutable form, which is thus of limited use in designing environments that conserve and preserve history. The activity-based environments allow one or more users to alter some character or element in pursuit of a defined goal, with similar interactions used in computer games, such as navigation within an environment and social interaction with embodied avatars. The third type is hermeneutic environments, which emphasise on the cultural aspect and provide a depth of affordance to users' interpretation of a natively residing culture and social perspectives. Based on the classification, we further focused the attributes of virtual objects into a framework that will be used in our research. These are visualisation, interaction and presentation in the pyramid of the VIP Framework of Virtual Objects (Fig. 23.2).

**Visualisation** presents an authentic physical object as digital representations. This involves 3D scanning, 3D modelling and the processes involved in the reconstruction of cultural heritage objects. The processes that lead to visualisation consists of components that include 3D meshes, textures and materials, and all that determines the visual, authentic appearance of an object. Similar to physical museums, different lighting and layouts do affect an object's appearance. This process only displays objects in a static and immutable form, which is insufficient for users to understand, learn and experience cultural contents as pointed out by Caggianese et al. (2014). We felt that visualisation is merely a first step towards replicating the experience of cultural heritage.

**Interaction** is a major factor towards an engaging virtual heritage environment, for it provides the key affordances for virtual objects to be interactive that would otherwise be static. The intrusive handling of museum artefacts is often restricted to

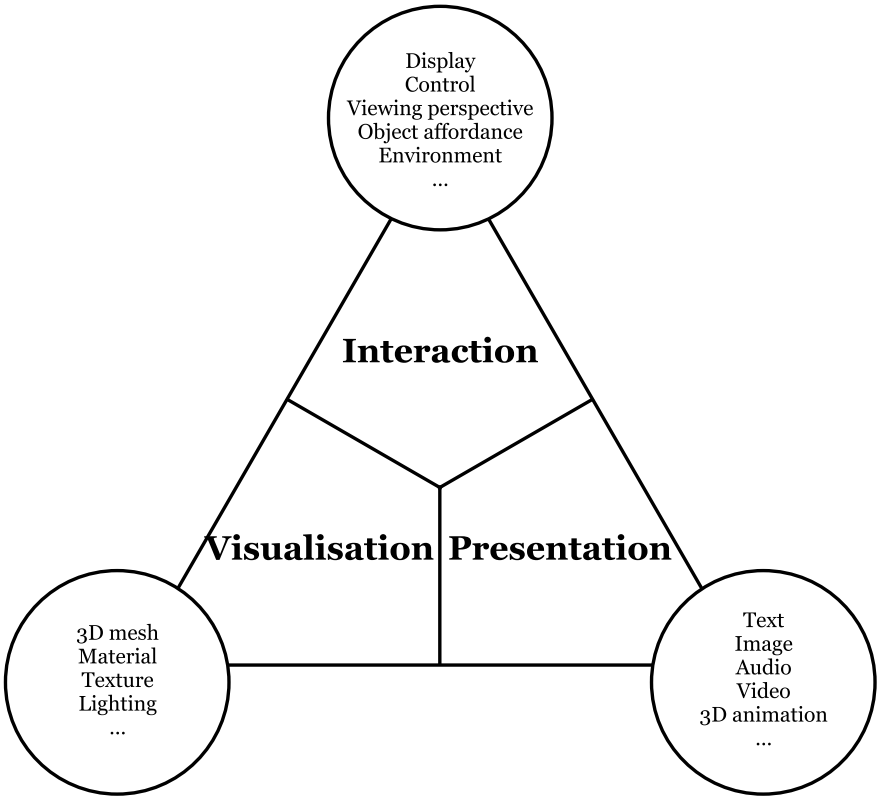


**Fig. 23.2** Visualisation, interaction and presentation (VIP) framework of virtual objects (Y. Li and E. Ch'ng)

a few selected objects. Virtual objects, on the other hand, offer flexible and diverse interactions as afforded by the display and control methods of the enabling technologies. For example, Bruno et al. (2010) designed rotation and zoom-up interactions for a collection of virtual objects to allow users to observe them in 360 degrees and in detail. Ch'ng (2013) further provides affordances for objects on multi-touch tables that include simulated physical weight, gravity, physics on cloth and affordances such as the conceptual connection of objects that are not possible in the physical environment. Interactions with virtual objects support users' learning from exploratory activities (Ch'ng et al. 2020) as well as their accomplishments of goals and tasks in activity-based environments. The design of interactions is thus essential for an environment to be engaging.

**Presentation** is distinct from visualisation in that it provides additional data that complements the artefacts. In museums, text labels, audio guides and video clips are used to introduce an object which includes information such as its name, historical periods, measures, purpose of use, cultural influence and stories. The presentation of object information can be easily integrated into the virtual environments or embedded

in virtual objects as digital technologies genuinely afford a rich array of media information. The presentation of virtual objects relates to hermeneutic richness (Champion and Dave 2007) in that it supports interpretation from users of different cultural and social perspectives. Presentation, in combination with interaction, can further facilitate meaning-making as a result of their interaction with it (Falk and Dierking 2000). The two attributes, interaction and presentation, can thus contribute to the hermeneutic virtual heritage environments.

Interactions with a virtual object are built on top of visualisation and presentation. The design of object interaction is informed by the visual appearance and physical affordances as indicated in the object's function, utilities and stories. For example, Gaitatzes et al. (2004) demonstrated the Ancient Olympic Games story with an interactive game—visitors were presented with an animation of an ancient Olympic contest once they put together the pieces of an ancient pottery vase. Such interactions can support the appreciation of an object's visual appearance (e.g., the vase) as well as the understanding of the associated information (the ancient Olympic contest). Interactions with virtual objects can support active engagement with objects within the environment. This satisfies the objective of virtual heritage research that provides educational experiences through manipulations of time and spaces (Ch'ng 2009; Stone and Ojika 2000). Therefore, we believe that it is through interaction design that we define the uniqueness and advantage of virtual objects. This should be different for each project.

## 23.3 Contextual Experience Cycle of Virtual Exhibitions

Interactions with objects and with other users are known to be closely linked to positive user experience within virtual exhibitions. Virtual exhibitions aim to convey meanings, significance and cultural values all within the scope of a visitor's learning experiences (Lester 2006). A useful method for understanding user-centred learning is Kolb's (1984) Experiential Learning Cycle. Kolb considers the continuum of perception and processing and identified four stages of learning: concrete experience (feeling), reflective observation (watching), abstract conceptualisation (thinking) and active experimentation (doing) (Fig. 23.3). The Experiential Learning Cycle emphasises the dominant role of an individual in the learning experience. Despite Kolb's theory being holistic and informative in understanding the cognitive learning process, it is less helpful in informing the design of interactions and the evaluation of experiences with objects and the situated environment, especially when XR becomes the focal technology. It is not clear how objects, the environments and other subjects may affect one's process of learning.

Dissimilar to the user-centred perspective that the Experiential Learning Cycle has taken, Falk and Dierking's (2000) Contextual Model of Learning highlighted the significant role that contexts play in the interactive experience with objects in museums (Fig. 23.4). They proposed that contextual considerations are significant, but often missing in traditional models of learning. Falk et al. (2006) advocated the

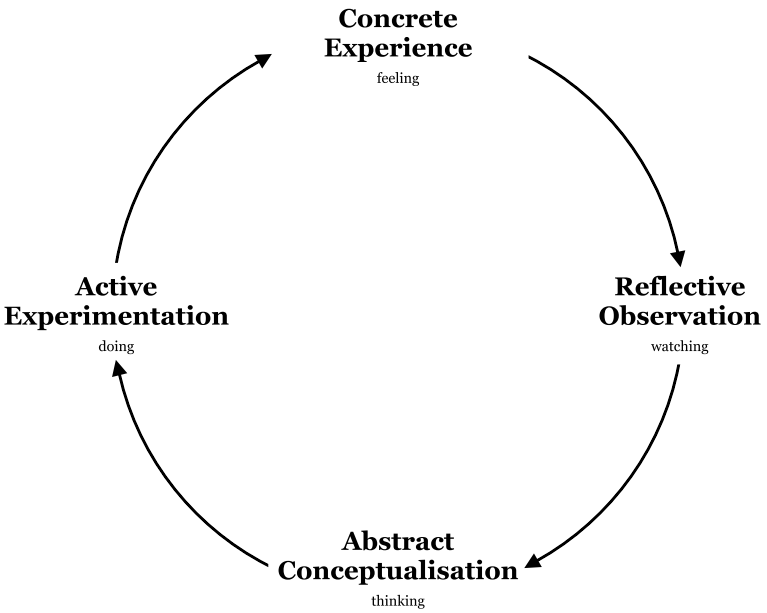


**Fig. 23.3** Experiential learning cycle (Kolb 1984)

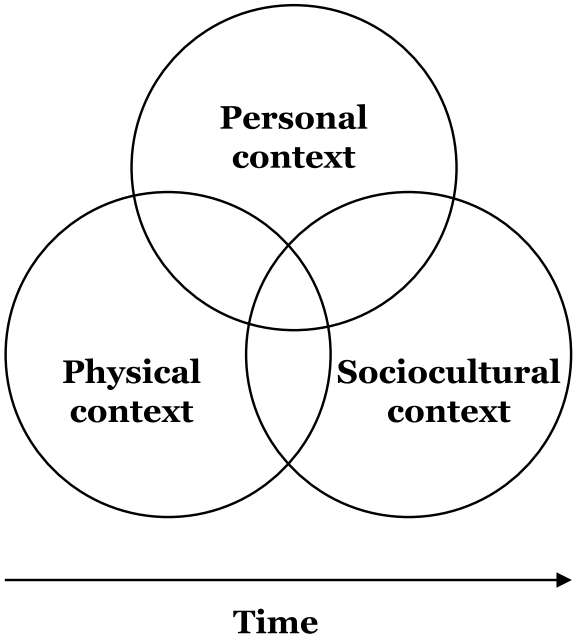


**Fig. 23.4** Contextual model of learning (Falk and Dierking 2000)

use of free-choice learning to describe the learning and experience of objects that might occur in the museum. Free-choice learning proposes nonlinear, personally motivated, and personal choices for deciding when, where, why and what to learn. The Contextual Model of Learning described learning experience as a process/product of the interactions between the following three contexts:

- **Personal context**, implying everything that the subject brings to the environment, including their motivation and expectations, interest, prior knowledge and experience, and preferences of choice and control.
- **Sociocultural context**, encompassing factors that recognise that learning is both an individual and group experience. It indicates that learning is influenced by within-group mediations and facilitated by others.
- **Physical context** explains the fact that the learning experience is rooted in objects and the situated environment. It includes the sights, sounds and smells, as well as the design features of the experience.

Dierking (2002) stated that the process of free-choice learning with objects is a situated dialogue between a subject and the environment. Over time, these three contexts support the construction of knowledge. Falk and Dierking's model supports the understanding of virtual exhibition experience as an overall process through the lens of contexts. However, it does not indicate users' subjective perception of activities during the process. Although relationships between objects, environments and other subjects were implied in the three contexts, an explicit analysis is needed to understand users' process of meaning-making. Therefore, we combined the two frameworks as the Contextual Experience Cycle of Virtual Exhibitions (Fig. 23.5).

The Contextual Experience Cycle of Virtual Exhibitions describes user experience of cultural heritage as an iterative process, segmented based on the relationship between subject, object and environment using a user-centred approach. The process involves a subject's interaction with the external environment, and the engagement with objects and environment that generates understanding. It includes communication with other subjects that invokes the expression of subjective interpretations.

**Interaction** refers to the direct physical actions between a subject and the external environment, such as the viewing and manipulation of objects. Virtual objects differ from physical objects in their technological affordances, such as the interaction possibilities and augmented information that are contextual to the object. Hein (1999) argued that interactions with objects allow for a constructivism approach that encourages the active participation of the visitors. Users' interactions with objects and environments are therefore a fundamental need for virtual exhibitions.

**Engagement** refers to the active, goal-directed, flexible, constructive, persistent, focused interactions with the physical and social environments (Furrer and Skinner 2003). While interaction concerns the physical actions of users, engagement relates their psychological states (O'Brien and Toms 2008). This means that internal thoughts and feelings are produced in the understanding of cultural heritage through engagement. Engagement primarily indicates the relationship between a subject and the objects/environments but may also involve other subjects if they are situated in

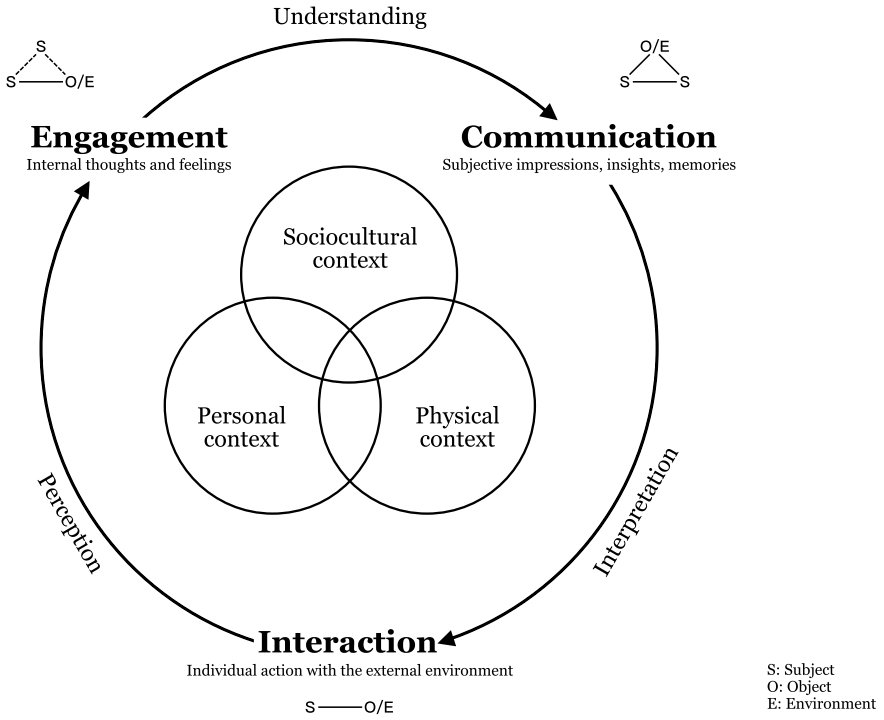


**Fig. 23.5** Contextual experience cycle of virtual exhibitions (Y. Li and E. Ch'ng)

the same social environment. It refers to a quality of user experience that can reflect the subjective evaluation of a digital environment (O'Brien and Cairns 2015; O'Brien and Toms 2008). Engagement has been identified as a major factor of the success of virtual heritage, in terms of users' emotional and social connections, explorations and learning through realistic visualisations (Tost and Champion 2007).

**Communication** occurs when users interact with each other, and when they share thoughts and subjective interpretations. Communication plays a significant role in museum visitor experience as most visitors visit as a group in the west (Bitgood 2011) and also in the east (Ch'ng et al. 2019a). Similarly, the use of technologies should support group communication as it can form an essential part of the social environment for free-choice learning (Falk and Dierking 2000). Jacobson and Holden (2005) argued that the reconstruction and visualisation of cultural heritage should ultimately be used as an interface to develop interactive narratives and communication potentials. However, previous virtual exhibitions barely support sociality and group communication, which are nevertheless necessary for mass dissemination and use of virtual heritage (Tan and Rahaman 2009).

In Kolb's (1984) Experiential Learning Cycle, learning is the most effective when all stages are involved but that is not often the case. Similarly, the experience of virtual exhibitions is the most positive when communication and sharing are

supported in parallel with object interaction, and when users can engage with the physical and social environment. In prior research, we observed that subjects may enter at any stage of the cycle and each stage is influenced by the three overlapping contexts throughout time. Our proposed framework is informed by research from two studies—a multiuser hybrid VR and AR environment with 52 paired users (Li et al. 2018), and the evaluation of the effects of VR environments on the acceptance, experience, and expectations of cultural heritage learning with 61 participants (Ch'ng et al. 2020). Further unpublished research on experimentation with hybridity contributed to the solidification of the framework proposed in this chapter.

## 23.4 Designing the HVAR Environments for Sharing Cultural Heritage Objects

There are three steps toward the designing of HVAR environments for the sharing of cultural heritage objects. The steps are based on the three attributes of virtual objects described in Sect. 23.2:

1. The reconstruction of virtual objects for **visualisation**
2. The preparation of virtual objects for **presentation**
3. The design of virtual objects for **interaction**.

In our particular research, we reconstructed six cultural heritage objects (Fig. 23.6) and created a multiuser environment that supports the hybrid use of VR and AR in a session that connects, in our case, two users.

We reconstructed six virtual objects using the digital close-range photogrammetry technique (Ch'ng et al. 2019b). Considering the different computing capacity of desktop VR and mobile AR, we used a simple retopology technique, a process of remeshing the geometry of a model in combination with texture-baking in a way that reduces polygon count but retains the qualitative appearance of the original model. This optimises the models for cross-platform, real-time usage in both VR and AR. The presentation information of these virtual object was collated from museums, websites and includes texts, images and audios. These processes lay a foundation for our interaction design. Table 23.1 summarises the interaction comparisons between desktop VR and mobile AR. These two types of technologies cover the two major platforms in general use, i.e., desktop and mobile, and are a good representation of the typical devices used for VR and AR. We have discussed control methods for mobile virtual exhibitions in Li et al. (2019b).

Social interaction is the key feature of our HVAR system. VR users are donned with a headset with the accompanying hand-held controllers. These provide users with full immersion and embodied interaction made possible by the tracking of movements via the headset and handheld controllers. Users interact by picking up and putting down virtual objects using the controllers within the VR environment (Fig. 23.7). On the other hand, AR users were provided with a cube consisting of six faces, each measuring 6 cm and containing an image pattern that a cultural heritage

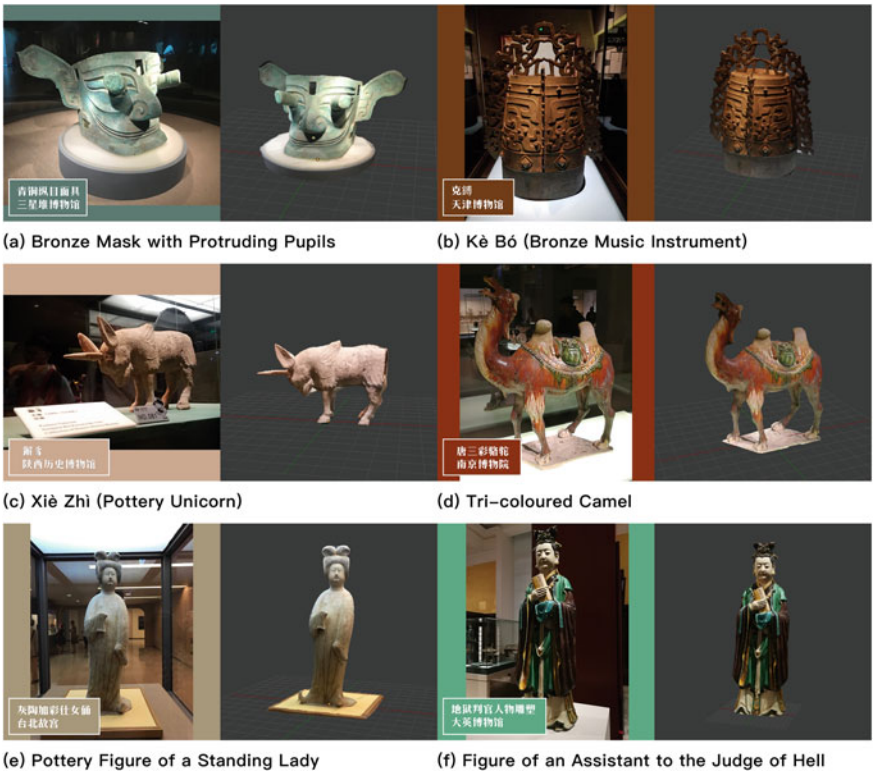


**Fig. 23.6** Cultural heritage objects side by side the physical original and the virtual copy (Y. Li and E. Ch'ng)

**Table 23.1** Comparison of interaction design in desktop VR and mobile AR

| | Desktop VR | Mobile AR |
|---|---|---|
| Display | Immersive Head-Mounted Display (HMD) | Flat-screen Hand-Held Display (HHD) |
| Control (Tracking) | External and built-in sensors | Camera-based tracking |
| Control (Inputs) | Hand-held controllers and HMD | Touchscreen |
| Viewing perspectives | 6 DOF with tracked HMD and controller | 6 DOF with tracked camera |
| Object affordances | Supported by body movements and navigation control | Limited support due to restricted display and control methods |
| Environments | Objects in simulated environments | Objects superimposed onto the real world |


**Fig. 23.7** VR control of virtual objects with hand-held controllers (Y. Li and E. Ch'ng)

object is augmented with (Fig. 23.8). Users view digital objects using a smartphone supporting interactions via touchscreen controls. Within the HVAR, virtual objects are used as an interface between VR and AR and the object itself becomes the connection between synchronised user interactions in HVAR. Virtual object rotations are synchronised in both environments, providing visual cues for each user on how the object is being manipulated by the other user. Aural cues are triggered when

**Fig. 23.8** AR control of virtual object with the AR cube (Y. Li and E. Ch'ng)

objects are interacted with for both VR and AR. Users in both environments can converse with each other at any time during the experiment.

## 23.5 Evaluating the HVAR Environments for Sharing Cultural Heritage Objects

We conducted a user study on the HVAR system described in the previous section, with 52 participants at the NVIDIA Joint-Lab on Mixed Reality, at the University of Nottingham's China campus. Our user study involved paired users in each HVAR session, one in VR and the other using AR (Fig. 23.9). As part of the communication aspect of this study, participants were asked to discuss two topics during their experience of the virtual exhibition:

1. the object you like most
2. the historical chronological order of the six objects.

Our study provides an indication of how HVAR is acceptable for sharing cultural heritage objects. It demonstrates the significance of social influence on the behavioural intentions of users (see Li et al. 2018). This study also demonstrates how the social nature of museum visits can be transferred into HVAR, and how virtual objects can mediate interaction and communication. In this section, we present an in-depth qualitative analysis of the observation and interview data and evaluate user

**Fig. 23.9** Paired users looking at a shared virtual object in HVAR, one in VR using the HTC Vive (right), and the other with the smartphone AR application in combination with the AR cube (Y. Li and E. Ch'ng)

interaction, engagement and communication using the Contextual Experience Cycle of Virtual Exhibitions.

We first applied the Contextual Experience Cycle of Virtual Exhibitions to understand the process of meaning-making in virtual exhibitions with a user-centred approach. We considered the personal, sociocultural and physical contexts of learning (Falk and Dierking 2000), we also analysed the relationships between objects, subjects and environments via their actions and dialogues. Finally, we mapped these data to the three stages of the framework: interaction, engagement and communication.

The snippet below describes an experience with the *Assistant to the Judge of Hell* object, where we observed communication and meaning-making between users. We begin with the AR user's interaction with the object, to the initiation of the conversation by the VR user, and through to the mutual engagement and interaction with the object. Brief personal experiences are observed.

| | |
|---|---|
| *[AR user triggered the augmentation of the Assistant to the Judge of Hell]* | **I-Eo*** |
| VR: *'Are you also looking at this one (the Assistant to the Judge of Hell)? [try to grab the object] It's heavy, I can't pick it up.'* | **I-Eo/Es-C** |
| AR: *[read the label] 'Yes. It is a she. So special.'* | **I-Eo/Es-C** |
| VR: *'What? [read the label] Oh I got it. Yeah, she even got earrings. It is special.'* | **C-I-Eo/Es-C** |
| AR: *'Yeah, it's rare to see ancient female statues, especially in hell.'* | **Eo/Es-C** |
| VR: *'British Museum. . . Why didn't I see this when I went there?'* | **Eo/Es-C** |
| AR: *'You won't remember everything even if you've seen it. British Museum is too big.'* | **Es-C** |
| *[continue talking about the previous visit to the British Museum]* | **Es-C** |

***I**: Interaction, **Eo**: Engagement with objects, **Es**: Engagement with subjects, **C**: Communication

**Interaction**—The AR user first triggered the augmentation of the *Assistant to the Judge of Hell* object on the cube, which resulted in the matched rotation of the same object in VR. The VR user then noticed the change in the situated environment (physical context) and proceeded to grab the object. Both users in AR and VR viewed the object (visualisation) and interacted with the information label (presentation) to understand the information of the object.

**Engagement**—Engagement proceeds from interaction with the virtual object, and learning occurs when individual users began to acquire knowledge on the object's properties such as its scale, weight, appearance and the host museum. The sharing of how they have understood the object is observed (sociocultural context).

**Communication**—Engagement between users and objects leads to personal interpretations, all of which were communicated verbally. For instance, the AR user found the object special due to the object's gender (i.e., female). The VR user then associated this observation with her previous visits to the British Museum (personal and sociocultural context).

The following example illustrates a process of meaning-making as a result of the mutual interaction of users with the *Pottery Unicorn* object. A shared understanding

is created through the co-exploration of the object and its affordances. The mutual interaction with a feature of the *Pottery Unicorn* object, i.e., its horn reinforces understanding. Such a connected experience can contribute to the AR user's attempt at interpreting the object.

| | |
|---|---|
| AR: *'Hey, go and check out the pig. It's so cute.'* | **I-Eo/Es-C** |
| VR: *'What pig? Xie Zhi? It's a unicorn!'* | **C-I-Eo/Es-C** |
| AR: *'Unicorn... I didn't know unicorn is in the Chinese culture.'* | **Eo/Es-C** |
| VR: *'It says that it's a beast that symbolises justice... the sinner will be killed by the horn... ' [grab and observe the horn, try to use the horn to attack the Figure of a Standing Lady]* | **I-Eo/Es-C-I** |
| AR: *'Be careful! Don't break it!'* | **Eo/Es-C** |
| VR: *'Ha-ha I just wanted to see what would happen. Clearly there is no interaction allowed here.'* | **Eo/Es-C** |

**Interaction**—The AR user looked at the *Pottery Unicorn* object (visualisation) and proposed that the VR user move the object in the virtual environment (physical context). Both users then read the information label (presentation) to obtain information. The VR user explored affordances of the *Pottery Unicorn* object by interacting with the horn and the *Figure of a Standing Lady* object in the virtual environment. This observation suggests that there is an awareness of the physical context associated with the object.

**Engagement**—The AR user falsely perceived the object as a pig before the VR user, in reading the object label corrected the AR user that it is a unicorn. The AR user assumed an understanding of the object from prior knowledge about Chinese culture (personal context). The VR user, on the other hand, acquired knowledge from reading the object label (presentation), which led to the exploration of the object affordances (physical context).

**Communication**—Communication initiated by the AR user helped the VR user understand the object better, which contributed to further interaction within the object in the virtual environment. Furthermore, the AR user shared a personal thought, that the virtual object should not be broken and further expressed objection to the VR user's intended action (sociocultural context).

By applying the Contextual Experience Cycle of Virtual Exhibitions to the analysis of user experience in HVAR, we found that the three contexts do contribute to the collective understanding of the learning process. At the same time, the user-centred approach helps in identifying the stages of interaction, engagement and communication within the learning process, presenting the differences between VR and AR users. The experience described in the first example demonstrated how communication in the hybrid environment can contribute to learning. The second example showed how interaction and observing the partner's interaction with virtual objects influence the process of meaning-making.

Here, we summarise a list of themes and apply a theme-based content analysis (Neale and Nichols 2001) in our research to further understand the interaction, engagement and communication in the hybrid use of VR and AR. Table 23.2

**Table 23.2** Interactions with objects in HVAR

| Theme | User | Action and dialogue | Pair ID |
|---|---|---|---|
| Shape (5) | VR (2) | *This cow (unicorn) looks unique.* | P3 |
| | | *I'm gonna use the cow (unicorn) horn to 'kill' you* | P13 |
| | AR (3) | *Hey, go and check on the pig (unicorn).* | P9 |
| | | *Check on this pig (unicorn)!* | P13 |
| | | *The cow (unicorn) is adorable.* | P16 |
| Colour and texture (12) | VR (7) | Comment on the detailed looks of the objects (assistant and camel's colour, lady and music instrument's texture). | P1, P7, P9, P11, P18 |
| | | Try to feel the texture of the music instrument using controllers. | P14 |
| | | *Why is this Tang artefact (lady) so pale? Shouldn't it be more colourful?* | P22 |
| | AR (5) | Comment on the detailed looks of the objects (mask's look, camel's colour, instrument's material). | P2, P10, P12, P19, P24 |
| Affordance (14) | VR (13) | Put on / wear the mask. | P4, P11, P15, P20, P25 |
| | | Use the horn of the unicorn to 'attack' other objects. | P9, P11, P13, P15 |
| | | Try to put an object on the ground (camel and lady). | P18, P25 |
| | | Try to break an object and see what will happen. | P19, P20 |
| | AR (1) | *I want to hear the sound (of the music instrument).* | P7 |
| Size and weight (6) | VR (6) | *It (assistant) is heavy, I can't pick it up.* | P1 |
| | | *It (camel) is huge.* | P3 |
| | | *I think this (lady) looks much smaller than the one I saw in the museum.* | P9 |
| | | *We should work together to lift it (assistant) up.* | P25 |
| | | Feel scared when picking up the camel (because of the size). | P15, P19 |
| Environment (8) | VR (8) | Walk around the pedestal. | P9, P21, P22 |
| | | Try to avoid bumping into an object. | P15, P19 |
| | | Try to put controllers on the virtual pedestal. | P9, P20 |
| | | Try to put multiple objects on one pedestal. | P22 |

sumarises the interactions in HVAR between subjects and objects, and Table 23.3 lists the engagement and communication in HVAR between subjects.

## 23.6 Discussion

### *23.6.1 Interactions with Objects*

In our observation, we noted that AR user tended to interact with objects based on their shape, colour and texture. Both VR and AR users initiated conversations by describing the appearance and name of the object so that both users are matched with the right object. In addition to the visual modes embodied in the visualisation and presentation of virtual objects, VR users fare better at the perception of affordances attributed to the model, especially in the object's use, size and weight, as well as within the situated environment. For example, many VR users have attempted to 'wear' the *Bronze Mask with Protruding Pupils* object or explored affordance with features of an object, such as the horn of the *Pottery Unicorn* object. The size of an object translates to users as weighty, i.e., users have commented that some models such as the *Assistant to the Judge of Hell* object were too heavy to lift.

As compared to the mere object augmentations in AR, the spatial layout of objects in VR has supported the physical context in users' learning of cultural heritage objects. In addition, embodied interaction (Li et al. 2019a), whereby user head and torso movements tracked by controllers are mapped to the virtual environment, does contribute to engagement in VR. Users commented in the interview that the immersive display and action possibilities of VR have significantly contributed to their experience in their learning of cultural heritage objects.

### *23.6.2 Engagement and Communication Between Subjects*

In terms of user engagement and communication, VR users tended to more frequently attract the attention of their AR partner than the other way around. This was due to a large screen display showing the full view of the VR user's virtual environment, while VR users were only able to sense interactions of the AR user from object rotations and sound effects. This limitation highlighted the need for better indicators for VR users.

Users in both VR and AR have prior knowledge of the objects on display, and both have shared personal experiences, which collectively contributed to their learning experience. Communication here is a key factor. The most prominent example was the use of the 'Tang Song Yuan Ming Qing' (a verse of Chinese dynasties) to justify their rankings of the historical chronological orders of objects (please see Sect. 5 for details). Users have also shared their subjective interpretations, mentioning the

**Table 23.3** Engagement and communication between subjects in HVAR

| Theme | User | Action and dialogue | Pair ID |
|---|---|---|---|
| Attract attention (17) | VR (13) | Check if the AR user sees him/her. | P1, P4, P5, P7 |
| | | Check if the AR user is looking at an object. | P2, P8, P9 |
| | | Ask the AR user to look at an object together. | P8, P14, P19, P26 |
| | | Ask the AR user to watch an interaction (wearing a mask, swapped th eobjects, using one object to interact with another, etc.) | P7, P21 |
| | AR (4) | Ask the VR user to look at an object together. | P4, P19 |
| | | Check if the VR user can see the rotation. | P12, P18 |
| Knowledge and personal experience (22) | VR (12) | Use the verse of Chinese dynasties to help rank the chronological order | P1, P3, P7, P13, P17, P19, P23 |
| | | Discuss why the assistant statue is at the British Museum. | P1, P8 |
| | | Ask their partner if a face looks like a friend of them (lady and assistant). | P14, P26 |
| | | *Was this one (mask) on the National Treasure show?* | P2 |
| | AR (10) | Use the verse of Chinese dynasties to help rank the chronological order | P2, P8, P10, P14, P18, P20, P22, P26 |
| | | *I've seen another one (mask) at the Jinsha Museum, but that one does not have the protruding eyes and such huge ears.* | P12 |
| | | *I remember I've watched a documentary about this (mask). These are really important for Chinese history.* | P15 |
| Feel related to an artefact story (5) | VR (2) | Discuss how rare and special the statue of the assistant is (for being a female official in the hell). | P5 |
| | | Discuss the plump figure of the lady and the ideal qualities of Tang feminine beauty. | P22 |

(continued)

**Table 23.3** (continued)

| Theme | User | Action and dialogue | Pair ID |
|---|---|---|---|
| | AR (3) | Discuss how rare and special the statue of the assistant is (for being a female official in the hell). | P1 |
| | | *I wish I can have the magic sight and hearing (like the mask).* | P1 |
| | | *I guess I'll see her when I die. I'm a good guy. You see? It says she takes notes of people doing good things.* | P4 |
| Social norm and order (14) | VR (11) | Worried about 'breaking' the object. | P1, P6, P11, P14 |
| | | Ask the partner to stop messing around with objects. | P2, P13 |
| | | Swap the object positions and then put them back. | P3, P17, P18, P21, P25 |
| | AR (3) | *I really want to take a picture of you.* | P2 |
| | | *Oh it's falling! Put it back!* | P19 |
| | | *Be careful! Don't break it!* | P23 |
| Cooperation (8) | HVAR (8) | Ask the partner to help remember the historical period of an object. | P1, P3, P19 |
| | | AR user acts as a tour guide for VR user, reading the labels and explaining the stories. | P4 |
| | | AR user makes the assistant rotate so that the VR user can see the back of the assistant. | P24 |
| | | VR user asks the AR user to trigger rotation of an object (assistant and lady). | P8, P19, P26 |

relevant documentaries they have watched and experiences of past museum visits. They commented in the interview that the exchange of information and interpretations have contributed to their understanding of objects.

We have also observed users complying to social norms as they would in a museum. The most prominent was to 'not break' cultural heritage objects. We observed multiple cases where users have reminded others to 'not break the objects',

or have expressed a fear of accidentally 'breaking' the objects. They reported in the interview that the realism of the objects has convinced them that they were real, and that cultural heritage objects should be treated with respect even in virtual reality. Many users have tried to swap the position of objects in VR. In the end, they were put back to their original location before the experiment is over. In the interview, they expressed aversion in confusing other visitors if the objects were wrongly placed. This care for other users is a sign that social norms can indeed be transferred into virtual environments.

We have observed spontaneous cooperation even though we have not designed for it. For example, we noted a series of similar cooperative action on the *Assistant to the Judge of Hell* object. The object is made to be immovable in VR due to its size. Its positioning means that the back of the model will not be visible. Interestingly, as AR users can rotate objects, several pair of users have discovered this cooperative technique to allow the VR users to view the obscured back of the model. This spontaneity in cooperation has illustrated that users can become creative in taking advantage of asymmetric interaction so as to explore possibilities in HVAR.

## 23.7 Conclusion

In this chapter, we presented the Visualisation, Interaction and Presentation (VIP) Framework of Virtual Objects that can be used to model user interaction in Hybrid Virtual and Augmented Reality (HVAR) environments. We presented cultural heritage objects within our HVAR environment using three attributes associated with the access of virtual objects and evaluated how user interaction, engagement and communication would sit in the VIP framework. The chapter continued by presenting the Contextual Experience Cycle of Virtual Exhibitions combining two learning theories (Kolb 1984; Falk and Dierking 2000). Hybrid Virtual and Augmented Reality environments are a relatively unexplored landscape, and the model framework presented here serves to lay a foundation for future research where hybrid environments and devices can be used for co-exploring and co-learning cultural heritage objects.

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