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Exploration of the Mechanism of Perception-Presence Coupling in Immersive Cultural Science Communication

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Abstract. With the development of immersive technologies such as VR, AR and XR, cultural science communication is shifting from the model of information transfer to that of experience. Research has been conducted so far on the effects of immersive technology; however, it has not been fully understood how perception produces presence and helps construct cultural meaning. The purpose of this paper is to study the mechanism of perception-presence coupling in immersive cultural science communication. This paper proposes a Perception–Presence Coupling Model to explain how immersive technologies facilitate cultural science communication through the transformation of perception into meaningful experiences. Through literature synthesis and theoretical analysis, the study identifies three core mechanisms: perceptual amplification, contextual alignment, and embodied engagement. These mechanisms explain how multimodal perception contributes to the formation of spatial, narrative, and cultural presence, thereby facilitating knowledge engagement and cultural meaning construction. The Digital Dunhuang Cave 285 virtual reality project is discussed as an illustrative case to demonstrate the applicability of the proposed framework. The findings suggest that presence is a necessary but insufficient condition for cultural meaning construction, requiring additional interpretive support and reflective interaction. This study provides a theoretical foundation for future research and design practices in immersive cultural communication and digital heritage experiences.

Keywords: Immersive Media, Presence, Perception, Digital Heritage, Mogao Caves

1. Introduction

With the development of immersive technology and virtual reality (VR), augmented reality (AR), extended reality (XR) and interactive digital exhibition systems, the way scientific and cultural knowledge is spread among the public is also being transformed [1]. Immersive media do not use text, pictures and videos as their only mode of communication; rather, they are about experience, interaction and participation. Now, in museums, digital heritage projects, science centres and cultural exhibitions are drawing more attention from the public by providing exploration and experience of knowledge rather than just being informational. Therefore, immersive cultural science communication has gradually been applied in an innovative way to spread scientific knowledge and promote cultural understanding, education and other activities [2].

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Research abroad has shown that immersive environments can help people be more involved in their lives, learn better, etc. The idea of "presence" has been used by people to talk about their own sense of being present in these days. At present, most studies have concentrated on the results of immersion and have paid little attention to the internal process by which immersive experiences are formed [3]. Although perception is generally regarded as the sense basis for immersion, and presence is considered to be a typical state of mind, the connection among them has not been studied to date. Furthermore, in the background of cultural science communication, the function of presence can be extended to help people understand and make sense of culture.

To address the problem, this paper will investigate the mechanism of perception-presence coupling in immersive cultural science communication. Specifically, it will explore how multimodal perception helps to build the sense of presence and how various aspects of presence affect knowledge engagement and the construction of cultural meaning. Rather than considering immersion as a direct consequence of sensory stimulation, the proposed framework conceptualizes it as a dynamic process through which multimodal perception is transformed into meaningful experiences through the formation of presence. Methodologically, this paper will use the method of a review of the literature and theory. Based on the research results of immersive communication, perception theory and presence theory, the contributions of this paper are threefold. (1) To propose a Perception–Presence Coupling Model that explains the relationship between perception and presence in immersive cultural communication; (2) To identify three mechanisms, perceptual amplification, contextual alignment, and embodied engagement that facilitate the transition from perception to presence; (3) To illustrate the applicability of the proposed framework through the Digital Dunhuang Cave 285 virtual reality project [4].

2. Literature review

2.1. Immersive cultural science communication

Cultural science communication is the act of spreading scientific knowledge and, at the same time, transmitting cultural connotations, values, social interpretations, etc. [5]. Traditional science communication mainly transmits facts, but cultural science communication is about how to present knowledge in a way that aligns with people's culture. It will increase the accessibility of science among the public and inspire interest in the study of science for emotional reasons, so people are more willing to learn.

With the development of immersive technology, such as VR, AR, XR and digital heritage platforms, cultural-science communication has gradually moved away from the information model and now focuses more on experience [1]. The old mode of communication is often one-way transmission of information; thus, the new idea of immersive environments can have users explore and learn by participating in virtual spaces. Spatialisation, interactive narration and the participation of the body have been applied to new kinds of expression for difficult scientific and cultural knowledge.

Immersive technologies have begun to be used more and more often in the digital museum and other areas of cultural heritage protection. The above cases show that immersive communication is not only an extension of the technology for traditional media but also a change in the logic of communication from information delivery to experience construction [3]. Although previous research has examined how well immersive media can increase the interest and learning results of people, it has not been known how these immersive experiences are generated.

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2.2. Perception in immersive media

Perception is needed for a person to feel immersed in reality. In the environment of immersive media, people do not just look at pictures; instead, they are all around us and get to know life by experiencing things with all their senses [6]. Therefore, perception in immersive media should be regarded as a multi-sensory phenomenon that includes all kinds of sensory information, spatial awareness, interactive feedback, etc. The First Kind of a typical method for creating the illusion of a real world in Virtual Reality is visual perception. High-resolution images, three-dimensional reconstruction and realistic visual presentation can help people feel that the virtual world is close to them and has more meaning [7]. Auditory perception helps to build a sense of place for people by providing spatial sound, environmental sounds and other types of information; thus, they feel closer to the created world [8]. In addition to the above, space will also help people better grasp how large and how far away different places are. Three-dimensional Space Structure and Embodied Navigation can be used to give users a sense of being in the mediated Space [9]. Interactivity perception is what people do in terms of behaviour and how the system responds to it. At any time, according to the detection of gestures and changes in body language, one can construct a new world by making active modifications. The above are the attributes of the senses, which create an impression of immersion. Only through the senses can we not experience how others are "there", and more research is needed to explore how perceptual processes result in a sense of presence.

2.3. Presence theory

Presence has been used to refer to the psychological phenomenon of immersion in extended reality studies. Generally speaking, it is the sense of being present in a medium; thus, the concept of "presence" is that people feel as though they are actually there in the virtual world [10]. Based on the above research, it is known that presence functions are often employed to link technology features with people's thoughts and feelings.

Among the various types of presence, spatial presence is the sense that one is in a place in a virtual world. It is often affected by the reality of Space, the sense of touch, etc. Narrative presence is the degree to which users are emotionally and cognitively involved in the story of a medium; it can be explained as people's feelings and thoughts about narrative structure. In the field of cultural science communication, narrative presence is often employed to give people an experience of history and culture, rather than merely presenting information.

In this study, cultural presence is proposed as an extension of traditional presence theory. It refers to users' perceived connection with historical meanings, symbolic systems, and cultural identities within immersive environments. Unlike spatial presence, which emphasizes physical location, or narrative presence, which focuses on engagement with stories, cultural presence concerns the interpretation and internalization of cultural meanings.

3. Mechanism of perception-presence coupling in immersive cultural science communication

3.1. Multimodal perceptual activation

In immersive cultural science communication, the function of multimodal perception is to start the formation of the immersive experience. Traditional media are mainly for people to receive information; therefore, immersive Environments can gather many different kinds of senses and interactive feedback to create more complete and interesting experiences. By means of various

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forms of presentation such as pictures and sound, one can develop a stronger sense of the mediated environment. Multimodal perception is not directly related to the phenomenon of presence. Sensory information needs to be organised and interpreted in a way that is meaningful to give people a sense of "being there", so perceptual activation should be regarded as the basis for the formation of presence rather than the final goal of immersion [8-10].

The Virtual Reality Experience of the Digital Dunhuang Cave 285 is an illustrative model for the proposed framework. Previous research on the Digital Dunhuang project has demonstrated that high-resolution digital reconstruction, spatial audio and interactive navigation can greatly improve the perceptual level of user's experience in the virtual environment. The design features match the perceptual enhancement process outlined in this study as they provide visual, acoustic and spatial enhancement and decrease the psychological separation between the user and mediated environment [4].

3.2. Perception-presence coupling mechanism

3.2.1. Perceptual amplification

Intensification of perception is the enhancement of sensory richness that increases people's attention and sense of experience. Immersive Environments can give people many kinds of sensations in a continuous and synchronized way to be aware of the world they live in. Reasonable arrangement of space, good construction of sound, and timely updates are used to reduce the difference in sensory expectations before and after communication via technology and thus improve people's sense of presence. In the Digital Dunhuang case, users can see a detailed reconstruction of Cave 285 and enjoy the culture with high-definition pictures and high accuracy; this is not possible when visiting the site [11]. An increase in perception can raise one's awareness of the surroundings and be the basis for spatial presence.

3.2.2. Contextual alignment

Perception alone cannot form a sense of presence without the support of culture, history and narrative. Contextual alignment is the situation where one's senses are in accordance with what one has learned from experience about a particular place. When the perceptual cues and cultural narratives are in line with each other, people will consider the environment created by the media more believable. For example, in the Digital Dunhuang VR experience, the reconstruction of cave buildings, the content of murals and the sound of the environment are combined to give visitors the sense of stepping back in time [12]. Such an adjustment helps people feel as if they are in the virtual cave, and thus believe that it is a place with rich cultural heritage and history.

3.2.3. Embodied engagement

Embodied engagement describes the process through which users develop a sense of participation through interaction and bodily involvement. Unlike passive viewing, immersive environments allow users to influence the experience through movement, exploration, and interaction, creating a perception–action relationship. Through interactive exploration in the Digital Dunhuang experience, users become active participants rather than external observers [13]. The ability to control viewpoints, explore details, and interact with virtual elements strengthens the connection between self and environment, contributing to the formation of presence.

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Through these three processes, perception is transformed into multiple dimensions of presence, including spatial presence, narrative presence, and cultural presence. Spatial presence emerges from the perception of occupying a virtual environment; narrative presence develops through involvement in cultural stories and meanings; cultural presence reflects the deeper perception of historical significance and cultural connection.

3.3. Stability and deepening of the experience

Perception-presence coupling starts the experience of immersion, and presence needs to be maintained continuously to have meaning. It is expected that through continuous participation in the perception-action loop, one will be able to gather new sensory information, correctly interpret the surrounding environment, and thus adjust behaviour in the virtual world. At this time, the users will begin to feel that they have been engrossed for some time. Now, instead of just observing the environment, one can also go out and learn by doing, feel emotions in daily life, etc. With the stabilisation of presence, people will be more likely to engage in cognition and emotion. Stable presence is not necessarily an in-depth knowledge of the culture. Although immersive environments can create a sense of place and a narrative, it is still not clear how to extract cultural connotations from it. The limitations of the previous study will be introduced in the following section.

4. Mechanism discussion

The above perception-presence coupling framework has provided a theoretical basis for how immersive cultural science communication can give people a good experience. Rather than viewing immersion as a direct consequence of the development of technology, this system believes that it is a changing process in which the sense of presence is formed and thereby affects people's awareness of knowledge and cultural connotations (as shown in Figure 1).

First of all, the framework shows that perception is the basis of an immersive experience, but it does not affect users in a simple linear way. A lot of sensory information can be obtained through vision, hearing, space, interaction, etc., for a sense of presence. These perceptual elements will only be given some meaning by adding context and experiencing life in practice. Perceptual intensification, contextualization and embodiment are employed to create various kinds of consciousness for sensory information.

Secondly, the purpose of presence is to connect the sense of immersion with knowledge. When people experience spatial presence, they are more likely to be attracted to and feel close to the virtual world; when they form narrative presence, they can be deeply engaged with the story and its ideas. These experiences can improve attention, emotional participation and cognitive processing; thus, the scientific and cultural knowledge will be learned through experience instead of just being presented as information.

However, this paper also believes that presence should be regarded as a necessary but not sufficient condition for the construction of cultural meaning. A high degree of immersion may give people a sense of being in that place, both physically and emotionally, but it is not guaranteed that they will learn more about the culture. The Digital Dunhuang Cave 285 case is an example of this. Although immersive reconstruction can give people a sense of space and story by having them experience the environment of the cave and interact with digital replicas of cultural relics, it may be difficult for them to learn about the symbols, history and culture of these relics in depth. Further research is needed to explore how the mechanisms through which cultural meaning could be constructed could be improved for the transition from immersive experience to cultural meaning

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construction. Specifically, adaptive guidance, contextual explanation and interactive learning support can be used to facilitate audiences from various cultural backgrounds gaining a better understanding in an immersive setting.

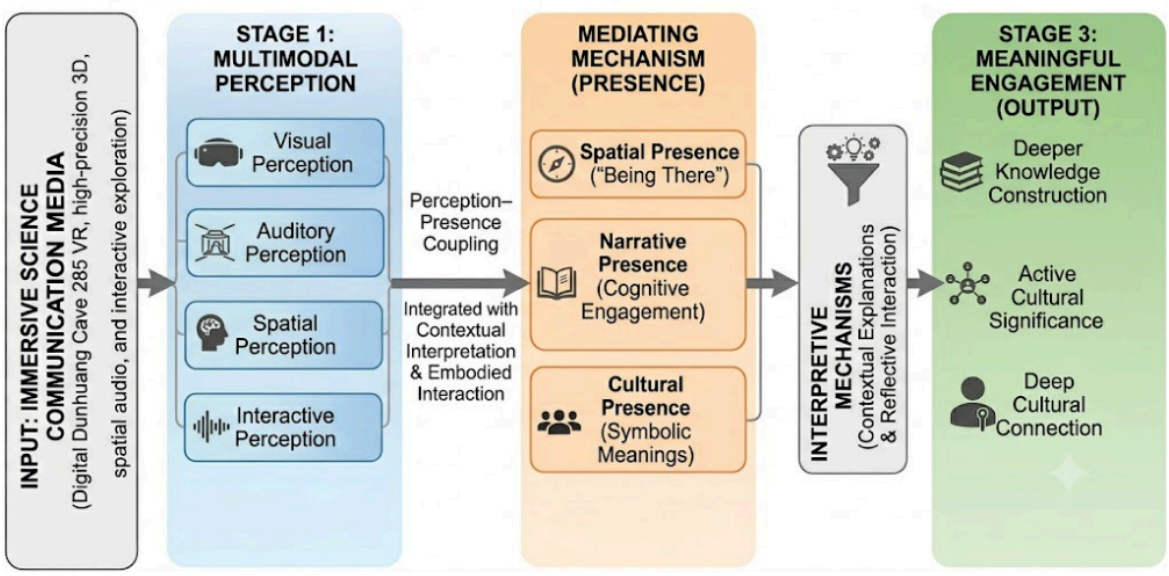

Figure 1. Conceptual framework of perception–presence coupling in immersive cultural science communication

5. Conclusion

A framework of perception-presence coupling is put forward in this paper to study the origins of good experiences in immersive cultural science communication. Immersive experiences do not directly originate from technological immersion; on the contrary, they are the result of all sorts of forms of perception, context adjustment and physical participation. Thus, perception has taken on many forms of presence to help us learn more about the culture. At the same time, this study also shows that presence is a necessary but not sufficient condition for the construction of cultural meaning; therefore, other interpretive methods are needed. This paper has some deficiencies. It is a concept study based on literature analysis and theoretical model construction; therefore, it has not yet been empirically verified. Digital Dunhuang Cave 285 is also in this group, so the results may not be generalisable to all other cases of immersive cultural communication. Some experiments will be carried out in the future to test and improve the proposed system in the following ways, such as user tests, behaviour analysis, cross-cultural studies, etc. Such research will help us better understand how the technology of immersion can make people feel things and learn.

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