The 4th Thailand International Symposium on Natural History Museums:
Era of Ecosystem Restoration, 17–27.

How natural history museums benefit from virtual reality (VR) technology to make learning media more memorable

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Article History
Received: 24 February 2024
Accepted: 16 June 2024
Published Online: 30 July 2024

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Abstract

This paper aims to discuss designing content for a VR exhibit that enhances episodic memory from analysis results of a study to investigate how a participant remembers the story of a VR exhibit. The design was considered the dominant feature of Head-Mounted Displays VR (HMD VR) that delivers a full immersive experience, an embodiment with the virtual body (VB) that induces sensory-motor function. The researcher conducted an empirical study which created a VR exhibit to deliver scientific knowledge about the camouflage of animals in a Tundra environment. The study used a mixed-method approach, quantitative and qualitative, to collect data for analyzing three factors: memory, emotion, and immersion, which focused on discussion in this paper. Fifteen subjects participated in the study. The results showed that the memory two weeks after the experiment did not significantly decrease from the memory after the experiment. It indicates that learners can recall the story of the Camouflage VR Exhibit at a high level. The results show learners' emotions have high levels of pleasantness and arousal, and the exhibit offers a sense of immersion to the participants with 2.90 from 5.00. The analysis of the qualitative data found nine design features that support learners to remember the Camouflage VR Exhibit's story, for example, game mission, objects in virtual environments, changing of the environment, critical situations, etc. This study suggests that natural history museums (NHM) should design the content of VR exhibits with experiential learning by creating experiences that allow learners to move their bodies to interact with a virtual environment rather than text explanations. This will aid to design experiences more actively by applying game mechanics, which the VR full immersive technology benefits from design content for NHM.

Keywords
VR exhibit, immersive technology, museum learning, user experience, camouflage

Citation. Phichai. 2024. How natural history museums benefit from virtual reality (VR) technology to make learning media more memorable. In *The 4th Thailand International Symposium on Natural History Museums: Era of Ecosystem Restoration* on 21–22 December 2023 at Rama 9 Museum Thailand: 17–27 pp.

Introduction

VR technology has great benefits in creating virtual environments of any ecological scenarios that simulate real-life situations or difficult or complex situations that might not happen or dangerous to experience in real environments. The majority of people interact with media via computer screens. Interactive media on screen deliver 2D experiences to players, where the players see the 3D simulated environment and are outside the virtual environment (VE). In contrast, HMD VR offers full immersive 3D experiences to the player where the player is inside the VE and moves their body to experience the VE. HMD VR completely replace the real world and enable players to interact naturally with the VE. Wildly discusses that immersive technology like VR enhances learners to remember stories (Cadet and Chainay, 2020). However, many factors influent on design a VR experience. This paper examines a way to design an experience for a VR exhibit which studies factors that enhance or might decrease the ability of player memory. This study transfers experience from a 2D touch screen exhibit into a VR exhibit in which content communicates about animal camouflage.

Background

Dioramas are the classic media for natural history museums to deliver 3D immersive experiences to visitors by simulating 3D environments of animal habitats. Once, VR technology was introduced, it can create any kind of environment. Experiencing through VR offers passive or interactive to learners which depends on the device and creates an experience. VR can be non-immersive like desktop VR which the player experiences VR through a computer screen, or full immersive VR like HMD VR which the player experiences VR by wearing the head-mounted displays.

HMD VR also has various features, one factor that makes the experience of HMD VR different is the degree of freedom (DOF). The three degrees of freedom (3DOF) can track a player's movement in three directions: head rotates side to side (Rolling), head rotates up and down along the vertical axis (Pitching), and head rotates left and right (Yawing). HMD VR with 3DOF is unable to track the player's movement. On the other hand, the six degrees of freedom (6DOF) allow HMD to track the player's movement and orientation. The 6DOF add more than three directions able to track from 3DOF including moving up and down, moving left and right, and moving forward and backwards. The controller is also able to track the player's hand movement.

The HMD VR syncs the player's movement and avatar that represents the player in the virtual environment, when the player moves hand, head, and body the avatar will move and pose accordingly. These abilities of 6DOF HMD VR allow the player to naturally interact with the virtual environment the same as they interact with things in the real world. Figure 1 shows a comparison of 3DOF and 6DOF HMD VR. VR with 6DOF induces more self-embodiment with the virtual avatar to the player. Avatar is an object to represent a player in the virtual world.

Another feature that benefits players when experiencing fully immersive HMD VR is that sense of embodiment. The embodiment of a user with an avatar in virtual reality (VR) refers to the sense of presence and identification a user experiences when interacting with a virtual environment through an avatar, and the player can control their avatar in the virtual world (Beaufils and Berland, 2022). Players feel a sense of ownership and agency over their avatars, leading to a psychological phenomenon where they identify themselves with virtual representation (Pratviel *et al*., 2022). Embodiment enhances interaction within the virtual environment. Users can perform actions and engage in activities as if they were physically present (McCreery *et al*., 2015). These features of HMD VR enable VR to support experiential learning (Kwon, 2021) and learning through HMD VR is a direct experience that is identical to learning in the real world (Kwon, 2019).

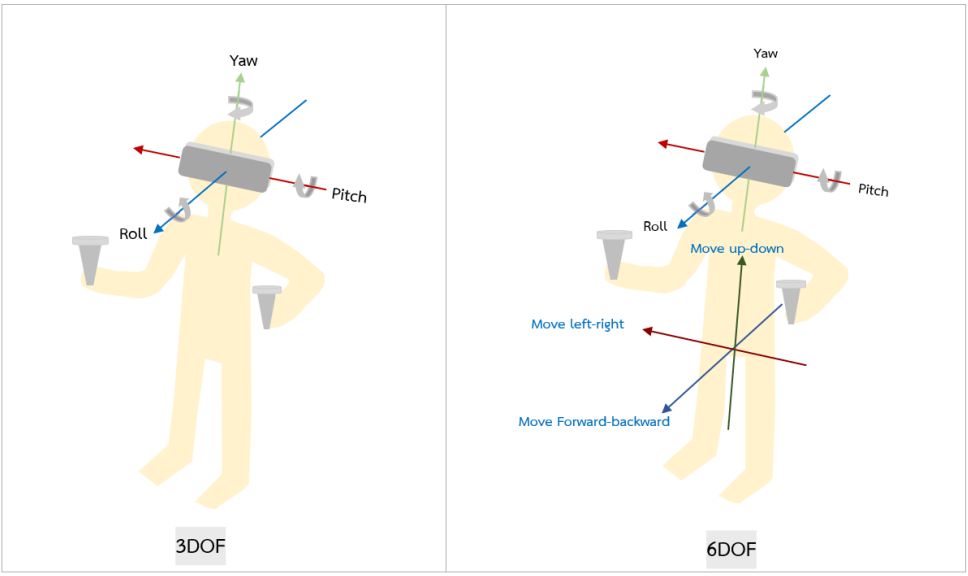

Figure 1. Degree of freedom of the VR HMD, comparing 3DOF and 6DOF.

Designing an experience for VR could be passive or active interaction. Active means players perform task actively with thing in VE, in contrast passive means players observe event or thing in the VE. Full immersive HMD VR support experiential learning or learning by interaction (Asad *et al*., 2021). In terms of passive and active experience with objects in virtual environments has been reported that players' interaction with virtual environments enhances memory, players tend to remember their action of the task rather than activities that they observe, and self-performance tasks also benefit from remembering spatial properties such as angle, size, and placement (Smith, 2019). However, Smith mentioned that increasing movement of the player's body (motor skills) might worse effect on episodic memory -memory of past events.

Immersive virtual reality enhances memory compared with non-immersive virtual reality as in Asad *et al*. reviewed. Immersion and presence are the properties of VR that create immersive experiences for players. Immersion refers to the capacity of technology stimuli players sensory, which is the influent physical character of the virtual world. Presence refers to the state of psychological sense of being there. Many factors in the design environment affect the immersion and presence of the VR experience (Cadet and Chainay, 2020). Designing media in a virtual environment for learning has various modalities. Some studies found audio modalities outperform visual modalities in supporting memory (Pillai and Yathiraj, 2017) while some studies found visual modalities more beneficial for memory than auditory modalities (Cohen *et al*., 2009). However, many researchers mentioned bimodal which involves presenting information through multiple sensory modalities simultaneously (such as auditory and visual cues) enhances memory (Liu *et al*., 2020) (Bonnici *et al*., 2016).

Researchers found emotions influence memory performance. Emotional experiences tend to be better encoded and recalled compared to neutral one (Tyng *et al*., 2017) (Cadet and Chainay, 2020). Emotional arousals refer to feelings that induce player more response to a stimulus in the player's environment, examples of emotional arousal such as anger, excitement, and fear. Much research found that stress affects memory, the stress bad effect on episodic memory (Shields *et al*., 2017). So, design experience in VR can induce emotions positively or negatively and that might affect memory differently. In short, many factors of the design VR experience might affect on player's memory which design an experience of a VR exhibit should concern.

Materials and Methods

The experiment used mixed method study, quantitative and qualitative. The researcher created a VR exhibit experience for participants to play. The VR exhibit delivers knowledge about the camouflage of Arctic animals in a Tundra environment applied from a touchscreen exhibit about camouflage in the Rama 9 museum. The narrative story of the VR exhibit adopts gamification techniques that change academic content into experience. The participant plays the role of an Arctic fox to survive in the Tundra environment for one year, seeking birds and escape from wolves. Each participant was invited to experience the VR exhibit and after each participant finished playing the exhibit, they were asked to give feedback on the memory test questionnaire. And after two weeks later, they will be asked to do the memory test again.

The memory test will assess the episodic memory of how the player can remember the story of the VR exhibit. It intends to investigate the retention rate after participants experience the VR exhibit. The measurement was created based on the content design for this VR exhibit, which includes examining the first part is the narrative story: sequence of the story, activities, and main point of the story that educates how animals camouflage by shedding their fur. The second part is the modalities of media including visual, text, voice-over text, and embodiment. It intended to examine how the modalities influent players to remember a story. The study also

measures players' emotions which believed aroused feelings from the wolves that attack player (fox) will help the player remember the story. It measured by using Affect Grid (Russell *et al*., 1989) which measure the player's emotion of arousal (alertness) and valence (pleasure). Immersion was measured to indicate immersive experience from the VR exhibit.

The study had fourteen participants joined the study. The following is the process of the experiment. The study setup in the experiment room is ready for each participant to experience. Before participants play the VR exhibit. The experimenter will explain the study to each participant, and require them to sign the consent form and answer information on the questionnaire about their demographics. And then allow them to experience the VR exhibit. After they finished their experience with the exhibit. Each participant will do a memory test. Then two weeks later the researcher contacted each participant via Zoom and asked them to do the memory test again via Google online form.

Figure 2. Example of touchscreen exhibit and HMD VR exhibit.

Results

Quantitative results

The results in this session show only a part that related to the memory test which focused on this paper. The whole results can be accessed in Phichai's research (2023). The statistical results show after experiment two weeks, the memories slightly decreased from the post-experiment memory except the remembered fox in summer slightly increased. Where the mean value of post-experiment memory is 5.378 (SD = 1.123), and the mean value of after two weeks memory is 5.147 (SD = 1.171). The mean value of memory difference between post and after two weeks is 0.164. To find significant differences between two points of memory by applying the Wilcoxon Signed rank test ($\alpha = 0.05$) between post-memory and after two weeks memory results show no significant difference between post-memory and after two weeks memory $\rho = 0.164$, $Z = -1.392$. It indicates that after two weeks memory did not significantly decrease from the after-experiment memory. It shows that the camouflage VR exhibit has the potential to support players to remember the story from the exhibit.

The results show high levels of arousal mean value of 6.933 (SD = 2.086) from 7, and a pleasant mean value of 6.467 (SD = 2.560) from 7, which indicates players have active good feelings toward the game. The results show participants immersed in the VR exhibit, a mean

value of 2.90 (SD = 0.791) from 5.

Figure 3 shows the details score of each question that participants responded to the memory test questionnaire. The result shows everyone can remember the hunter (wolves) in the story. They can remember the name of the bird in the story (Ptarmigan) at a high level, where the mean of post-experiment memory is 0.933 (SD = 0.25) and the mean value of after two weeks memory is 0.867 (SD = 0.352). Considering, that the players received the names of birds only via the text and voiceover text. The area that foxes were able to hide received the lowest score for some reason, where the mean value of post-memory is 0.550 (SD=0.194) and the mean value of after two weeks memory is 0.467 (SD = 0.186).

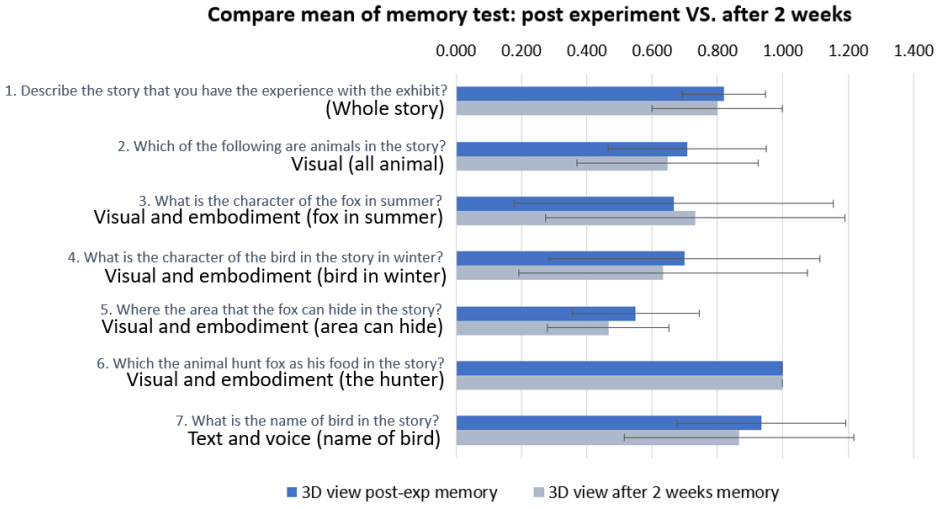

Figure 3. Compare mean value between post experiment and after two weeks memory.

Figure 4 shows the details score which breakdown the criteria for how the participants remember the whole story. There are three criteria: sequence, activity, and shedding of fur. It shows players can remember activities that they did in the game. Players can remember foxes' shedding fur at a high level. However, they slightly mention about shedding the fur of wolves and birds. Participants slightly could not remember the sequence of seasons in the game. It shows after two weeks score decreased from post-memory, especially during the winter season at the finished point, where the mean value of post-experiment is 0.567 (SD = 0.495) and the mean value of after two weeks memory is 0.467 (SD = 0.516). It indicated that the sequence of the story might be difficult for the players to remember.

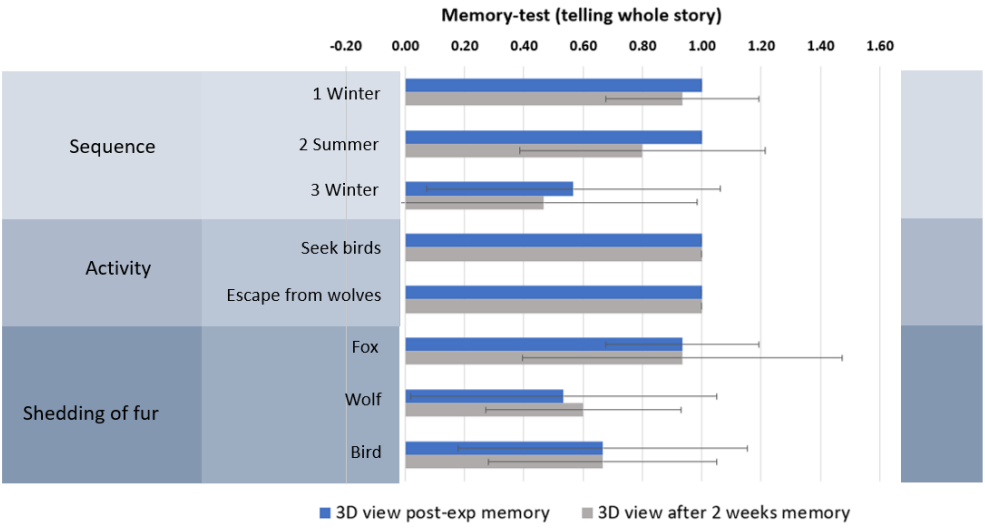

Figure 4. The detail memory score that participant telling whole story.

Qualitative results

All answers of open-ended questions in questionnaire were analysed by thematic analysis. This section will only show the theme that relates to memory, the more detail explained in Phichai's research (2023). Participants Reported that the features of the game help them remember the exhibit's story. Participants mentioned experience interacting with the virtual environment the most helps them remember the story. A participant stated the picture of running in the Tundra environment, seeking for birds to eat, and escaping the wolves sticks in the participant's memory.

Participants mentioned features that help them remember the story including 1) game mission which assigns them to do activities in the game. 2) things in the environment for example participant stated that they walked in the winter season and saw a lot of rock (U3D-05), they remembered the position of the shelter (cave) by stating the shelter was below underground (U3D-09). 3) they can remember the changing of the environment in the VE especially changing of colour in the environment for example changing of seasons from white winter to green spring. 4) text with voice-over instructions or animation with voice-over. They can remember some sentences in the instruction "…a long winter and shot summer…" which the game can not simulate this situation in the game. 5) critical situations affect players' feelings for example they remember the feeling of the situation when the wolf attacks them in the game and they try to run away (U3D-07). 6) transition of the game, sometimes they could remember how many stations are in the game instead of a sequence of the game (the sequence of season). 7) sound in the game, for example, they can remember the sound of the wolves

when it roars. 8) the size of things in the virtual environment, especially they can remember thing that is bigger than them or smaller than them for example the giant wolf, the big wall. 9) interaction with user interface (UI) for example the participant mentioned that they click a button on the screen and then the season in the game is changed (U3D-T01).

Discussion

The full VR immersive technology allows players to experience nature by themselves likely they live in that situation, and use their body to interact with the virtual environment which other technology might not offer. The VR offers NHM to simulate environments or situations with might not happen in reality or are difficult to create that environment for visitors to experience. For example, from this study the Tundra environment. This session will discuss the design feature of learning content that supports visitors remembering the exhibit story and the design feature might make a difficult for visitors to remember the story based on results from this study.

How can VR offer to deliver NHM content?

First, take advantage of the dominant features of HMD VR that allow players to use their whole body to interact with the VE. Participants almost reported they can remember the experience that they interacted with things in the environment. They can remember activities they seeking birds, and running away from wolves. So, should create activities that allow them to interact with things and environments in the virtual world rather than offer them reading text. Interacting with objects in VR does not offer a sense of touch however some research mentioned that the VR joystick offers a tangible experience to players (Phichai *et al*., 2021). This provides a feeling of real interaction with objects in the virtual world. It could simulate sense of touch to the player.

Take advantage of the dominant feature of HMD VR that provides a 3D environment to deliver the character of the environment, animals' habitat, and animal character. The virtual 3D environment that surrounds the player offers players spatial sense, or spatial perception. Spatial sense involves understanding the relationships between objects in an environment and one's own position within that space. This capability affects how human perceive distances, sizes, and spatial properties of objects (Ho, 2020). Consider experiencing desktop VR, player observe the virtual environment in contrast experiencing on HMD VR player stay inside the environment, so HMD VR provides players with spatial sense better than desktop (Azarby & Rice, 2023). Using HMD VR able design experience for comparing size of living thing in the nature. For example, from this study, the VR exhibit brings players to experience how hard to hunt birds with camouflage blended into the environment, players feel challenged to find birds and this situation brings them to understand the role of camouflage and remember the situation.

Using gamification technique that applies game mechanics to create experience through

HMD VR. Using role play with setup mission it offers natural history museums to bring visitors explore into the journey and understand living things life in the natural. It makes them remember, have feeling, and understanding living thing that they were imitating. For example, understand how the fox survive difficulty finding bird camouflage, escape wolf hiding inside cave. However, should carefully the fault of creating interaction and constraints in game will make the player misunderstand the situation with the wrong information which found in this study (Phichai, 2023).

Why cannot participants remember some features?

Players found difficulty in remembering the sequence of change environment. A research found that the length of the list and position in the list affect remembering, people can remember short lists more than long lists, and people can recall information from first learned and information learned last better than the middle of information that they have learned (Murdock, 1962). In this study some participants could not remember the sequence of season change in the game, it is only three orders of season. Considering that the transition between seasons is not clear at the end, that is the reason why the player cannot distinguish that the season has changed. Environmental context effects on episodic memory. A stable environment provides consistent contextual cues, which help in encoding and retrieving episodic memories, but changes or ambiguity in the environment can disrupt these cues, making it harder to recall the sequence of events (Barak *et al*., 2013). So, if want learners to remember the sequence or step of some process should make it clear.

Players have difficulty distinguishing the character or appearance of things that they could see in a short time. In this study the wolf randomly appears in the scene and randomly attacks the player. So, it makes the player cannot see the detail of the character. Also, the design of the game allows the player could see the wolves in a short time because they need to escape. Another point to mention, players might not see the difference in small changes while interacting with things in the game. For instance, from this study, the design of the fur's colour is quite similar before shedding fur and after shedding fur, the player cannot see the difference between wolf's fur in winter and summer season. So, designing learning elements in the game should consider these points.

Conclusion

This paper discussed a study to investigate the design features of VR exhibits that support players to remember the exhibit's story and design features might disrupt players' memory. The study created a VR exhibit that offers players to learn about animal camouflage. The player played the role of a fox that survives in Tundra environments for one year. The player needed to interact with the environment by seeking birds to gain energy and escape from wolves to survive. The study measured the episodic memory of the player two times, immediately after finishing playing the VR exhibit and two weeks later after experiencing the VR exhibit. The

study investigated three factors: memory test, emotion, and immersion. The memory test includes two parts: narrative story and media modality. Fourteen participants joined the study.

The results show participants' memory of experienced VR exhibit did not significantly decrease of memory after two weeks that they played with the exhibit. It indicated that the VR exhibit supported players to remember the experience from the exhibit (mean value of after experiment = 5.378, and mean value of after two weeks experiment = 5.147). Using thematic analysis of the qualitative data found nine features that support players to remember the story including the mission of the game, things and number of things in the environment, changing of environment, voice-over text sentence or word, critical situation, change state or scene of the game, sound in game, size of the objects, and interaction with UI.

In summary suggestions from this study, to deliver natural history museums content should create activities for players to interact with the environment rather than reading the information, create environment characteristics that players could have spatial sense from VR, and apply gamification to use game mechanics to create experience. However, carefully designed sequence of the story for player to remember, makes it clear when it changes state, designed for the player to remember the appearance of things that the player sees in a short time or randomly appear in the environment, those design participants report have difficulty to remember.

Acknowledgments

This work is a part of PhD Study in Computer Science at the University of Glasgow, UK. I want to express my gratitude to my supervisors, Assoc. Prof. Dr Julie Williamson and Dr. Metthew Barr for their guidance and support. Thank you for the sponsors, the Royal Thai Government Scholarship, Glasgow University funded, and NSM Thailand.

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