Remembering Mithras: Can VR be used to learn about the past?

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Chapter 1 **Introduction**

In the first century AD Seneca wrote “nothing is more deceiving than our eyesight”, thousands of years later with the invention of virtual reality (VR), this phrase still rings true with a new form of deception. A key feature of VR is that it allows the user to feel a sense of presence, or the psychological state of ‘being there’, inside an interactable 3D virtual environment (VE) that may look and act vastly different than the tangible world. This phenomenon can cause users to ask existential question such as ‘what is real?’ or ‘what is reality?’. When faced with a task of walking off a cliff edge in VR, many users are hesitant of doing so. While they know they are standing on the ground, inside of a room with a headset on, the visual feedback, seeing they are on top of a mountain causes the user to question that reality. This makes VR an incredibly powerful technology when thinking about displaying the past. A general complaint about historical sites is that nothing remains except the occasional ruin, most artefacts that are found from these sites get placed into museums, often located far away from the site itself. This makes past sites really difficult to interpret when looking at them, and it makes the objects in the museum seem out of place and disconnected. 3D reconstructions have been used in archaeology since the 1980s with the model of Roman Bath (Lanjouw, 2014). However, using these models in learning and academia have not been well researched. The true value in learning about the past is not known.

Importantly, this brings the topic of authenticity and truth in models, which is why this paper uses (re)constructions or (re)create to refer to these 3D VEs because most of the time, what is modelled is based on the most recent knowledge in archaeology and ancient history, but is always based on an expert’s judgement which could be incorrect. When placed into VR, the past becomes more ‘real’ to the user, and it will be important to have the user ask questions such as ‘what was true?’ and ‘what is the meaning of this experience?’ and ‘what have I learned from this experience?’. This paper looks at the temple to Mithras at the Roman fort of Carrawburgh on Hadrian’s Wall to test whether VR can be effective as a tool to learn about the past.

The initial plan was to test if adding multisensory effects (sound, scent, and haptic feedback) would increase learning and interactivity, however this was changed to test learning over time. This was done as a pseudo-longitudinal between-subjects experiment. Participants answered a learning questionnaire before, directly after, and 10 days after partaking in the experiment. A post-experience questionnaire asked the user about presence, sensory engagement, perceived historical accuracy, and how easy the experience was to use.

The research questions addressed in this paper are as follows:

- Is VR an effective way to learn about the ancient world?
- Could this learning be attributed to the feeling of presence in VR?
- Does the user retain the information they learnt over time?

The product: An experiment including a Unity experience that is a viable environment to test learning on participants. Technologies used: Oculus Rift and Touch Controllers, Unity, 3DSMax, Photoscan, VRTK, Arduino, C#, Oculus SDK, and Oculus Avatar.

Chapter 2 Background

Although VR head mounted displays (HMD) have been around since Ivan Sutherland's invention in the 1960s, it was only with Palmer Luckey's Kickstarter prototype of the Oculus Rift in 2010 that VR became mainstream. In the past 10 years, there have been many advances in both software and hardware that have been able to create compelling experiences for a consumer market. Therefore, it is not surprising that there are gaps in the literature, especially related to how to design an experience and interactions, and answering questions such as: is VR an effective way to view the past and does using VR promote learning? To answer these questions, this paper's research focused on how to display the past, presence, coherence, and learning.

2.1 Using VR to (Re)Create the Past

The traditional way of learning about ancient history is to be taught in a classroom setting, read sources relating to the subject, and if fortunate to go to a museum to see artefacts or to an archaeological site. With the addition of technology, videos or audio, such as those from educational radio, have also been introduced in learning. This immediately presents a severe limitation in learning about the past as it is known that everyday life and religion in the ancient world were embodied and sensorial experiences (Toner 2014). There is a sense of irony that such knowledge is reduced to words on paper, but VR is one way to bring the research and the past to life. However, VR is also limited, as it only engages three senses (sight, sound, and touch). Few companies have tried to (re)create past sites in VR, such as Rome Reborn and Lithodomos. These experiences typically offer extremely limited locomotion and interaction and rely heavily on the visual aspects and the fact that most users will not have been using VR much (personal communication with Rome Reborn, August 2018). Obviously, this view will need substantial changing if the business wants growth and to make a profit in the future, but for now it is understandable why they are focusing on the visual aspects. However, reviews of these products generally ask for open world exploration, sounds, a story, and interaction. However, as the Rome Reborn team found, offering such interactivity comes at a high cost with the amount of geometry of the scene (personal communication, August, 2018). Therefore they only offer specific places to teleport to, some audio that is rather misplaced, and the ability to look around 360 degrees. It was decided to approach the topic differently in this experiment, by giving the user the ability to freely walk around or teleport, interact with objects, and listen to the information of the cult relayed by the voice of the god Mithras. This experience necessarily thought about the sensory information from the start. It was originally anticipated that the experiment would test different sensory inputs, but in the end this did not work out.

Figure 2: Temple to Mithras, taken by author June 2018

The *mithraeum* at Carrawburgh was chosen as a case study because many people have never heard of the fort, the cult, and it is hard to interpret when at the site and is a relatively small temple. The spatial and temporal dislocation of the original objects and their find spot creates a dissonance between the temple and the artefacts themselves. As it sits today, it is difficult to understand how the Temple would have appeared and operated 1,700 years ago (Figure 2). It was decided to build the (re)construction as it would have been in the fourth century because this is how the ruins are viewed today. It was immediately decided to use VR as a display solution because VR allows multiplicity of representations, showing change over time, and a multisensory experience. Because the past was not just visual, VR helps re-imagine the objects inside the Temple that invoked a range of sensory reception.

Deciding *how* to display the content was an important part of this project and the justifications will be discussed in Section 2.3. Temples to Mithras were dark places that emulated a cave, the lighting would have had a dramatic effect, and enhance the sensorial perceptions. Visually, the iconographical scenery with its bright painting would have been lit by lamps or torches. Relating to audio, there was talking and chanting of initiates. In addition there would have been a burning of carbonized pinecones which would have emitted a strong pine scent (Richmond and Gillam 1951, 7). It is likely this scent was unique to the temple, and would have acted as a way to delineate the space. Scent is known to have a strong link to memory and emotion (Aggleton and Waskett 1999; Herz et al 2004). Because of this, it is likely that the burning of the pinecones in the temple would have heightened the experience and created a special memory to the place associated with the scent, and it is possible that a similar experience could be created using VR because the user will feel present and engaged, and perhaps remember more with various sensory modalities being added to the experience.

2.2 Presence Research

Skarbez *et al* have recently published a survey of presence, so it is not necessary to detail the topic here (2017b). Instead only the aspects of place illusion (PI), plausibility illusion (PSI), and coherence will be introduced because these are directly related to the topic of (re)creating the past in VR.

Slater divides the topic of presence into the PI the question of 'am I there?' and PSI 'is this happening' (2009). Slater tries to look into the hardware and the effects of the display, but these are also closely related to the content of the experience. When trying to display the past these two facets must be looked at. When the user asks 'am I there' inside a historical VE, the answer can be 'it seems like I am there and seeing what the past looked like' but when they also ask 'is this happening' there is a bit of a disconnect because what they are viewing is from a different time period, which in itself is a very alien culture, and the content of the experience may be different from what they know to be true from museums or textbooks.

Skarbez introduced the concept of coherence which looks into the content being presented in the VE and can be defined as 'the extent to which the virtual scenario behaves in a reasonable or predictable way' (Skarbez et al. 2017a). This means that the content should be congruent to what the user's preconceived notions are that relate to the experience. For example, in an experience that depicts a car driving along the road, the cars should be driving on the ground and if in America on the right side of the road, or in the UK on the left. The user would not feel the experience simulated the real world if the cars came from under the ground or were flying above their head.

Figure 1: Altar to Mithras from Carrawburgh. Left: Drawing of the original find (RIB, 1546).
Middle: Reconstruction of the original in the Great North Museum Hancock (taken by author).
Right: My polychromatic interpretation.

Relative to the past, coherence can be an issue as what society knows of the ancient world is not always factual, rather has been conflated by decades of incorrect information displayed in museums, research papers, and elsewhere. For example, artefacts in museums typically have no context and are depicted austere and almost complete pieces of art, but in the past they would have been painted in various colours, used in a specific way, and are often fragmented when excavated (Figure 1). In this experiment, it was necessary to present the material so it firstly was an accurate representation of the research on the cult of Mithras and Carrawburgh, but also abided by our specific cultural knowledge about the past. In order to create a believable experience, it was necessary to first look at the question how do people learn about the past, and can they learn in VR?

2.3 Learning Research

Due to the infancy of the technology little research has gone into the efficacy of using VR as a learning tool. There are three key works that have attempted to look at learning in VR. The first is Fabola and Miller's study that claims 'the efficacy of virtual reality as a tool for learning history has been demonstrated [in their paper]' (2016, 13). However, this is a misguided comment as they do not actually look at learning, rather they look at the usability of VR as a tool, students attitudes towards the medium, and the effects of using it. This is disappointing as the effectiveness of the technology should be investigated by looking at qualitative scores on a test, rather than just asking students if they would use VR in a classroom. Another key paper researched the direct manipulation of objects in a VE. Jang *et al.* have shown that when students are allowed to interact with the environment, they do better on the test (2017). The critique from Fabola and Miller's study is rectified here, however, there is a problem with the way users manipulated the environment as in this study a joystick was used rather than the hands or VR controllers. Finally, Bailey *et al.* looked into using VR for memory recall in order to prove user presence in a VE (2012). However, this only works if the content is concrete and able to be seen as they tested users recall of objects in a space. From these three papers, it was clear that more experimentation needs to be done. Therefore, this paper separates learning research into two parts. The first track of research related to (re)creating the past and the second was on educational theories to display the content.

In 2013, a user study about audience perceptions on Hadrian's Wall and the issues surrounding displaying the past was conducted (Adkins, Holmes, and Mills 2013; Mills 2013). The issues relevant to this paper are as follows:

1.) Current display methods do not use artefacts to help the viewer understand the past.
2.) There is a poor understanding of interpretation principles in the museum community.
3.) Museums tend to not look at wider context when displaying objects.

It is extremely rare to have photos of an archaeological site inside the museum, in relation to Carrawburgh, the artefacts from the site are found at the Great North Museum: Hancock in Newcastle, 27 miles from Carrawburgh, and at Chester's Roman Fort in the Clayton Museum, 6 miles from Carrawburgh. These artefacts are both temporally and spatially displaced and decontextualized. This makes it difficult to understand the role of the objects and site in the past, which is a perfect opportunity for technology to help. The VE can re-contextualize the displaced objects and give the user an idea of how the past site operated. However, care must be taken with this, because we will never be able to fully recreate the past as any (re)creation is limited by archaeological findings and current expert knowledge on the topic. This is why (re)create is used as a term to imply this concept. If knowledge of the past is changing and not concrete, this brings us to the second point could VR actually help people learn?

In order to answer this question, it must first be asked, *how do people learn?* For this experiment, e-learning and experiential theories of learning were used to create an experience. E-learning theory relies on the delivery of content, and there were a few points that were important for this study, the first was the Multimedia effect, that combining audio, visual, or text promotes learning, second was the

Coherence Effect, having the content fit the experience, and the pre-training effect, that is to explain the content before going into the experience (Mayer, 2003). For this study, the multimedia effect was used as sounds that accompanied the experience were used such as torches crackling as the user lit them and a man narrating as the voice of the god Mithras. During on-boarding the player was shown a map of the temple, and given a brief description of the task, and the fort. However, e-learning theory did not seem enough to work inside of VR as it has only been tested using 2D presentation methods. Therefore, experiential learning theory was also used. For centuries it has been established that experience is the best teacher (Caes. *BCiv* 2.8; Plin.,*HN* 26.11). Following Jang *et al.*'s direct manipulation study, it was decided to use experiential learning theory as the interaction inside the VE seemed to fit this well. VR facilitates an environment for experiential learning which emphasizes 'the central role that experience plays in the learning process' (Kolb et al. 2001). The efficacy of VR as a learning tool has been shown on numerous occasions in relation to practical or skills training, however, it has not been well presented as a tool to deliver content from the past.

Chapter 3 **Design and Requirements**

Because the process of using VR to (re)create the past is new, existing methodology is limited. Therefore, it was necessary to create a new methodology. First and foremost, this required understanding interaction techniques, learning theories, ancient history, and archaeological evidence. Secondly, it required 3D modelling of assets used in the experience. Thirdly, the transfer of the modelled assets into Unity to make a VR experience. It was important to then choose which headset to use. Ideally, the experience should work across all HMDs, however, because the only available headset was an Oculus Rift this became the core target. In the end, this was a good choice because developing to the Oculus Rift also has the added Oculus Avatar. The avatar was manipulated so the user could look down and see a capsule that looked like a body. The biggest benefit of the Oculus Avatar is that it has hand models that are reactive to the users interactions with the Oculus Touch controllers. This embodiment adds to the experience and allows the user to act more naturally in the VE. The fourth aspect of the project was to add VRTK. Of these four steps, the 3D modelling and understanding archaeological evidence and ancient history was done prior to the start date of the project.

Before the start date of the project, I looked at the archaeological record and found the necessary information about the site. It is important to note that Newcastle University Digital Humanities provided the scans of Cautes and Cautopates (two statues in the experience), the Society of Antiquities of Newcastle Upon Tyne provided the original image for them, and Alberto Foglia allowed me to use their 3D scans and re-painted models of Cautes and Cautopates. The cult statue, was also a photograph of the statue found at Houseteads Roman Fort now displayed in the Great North Museum Hancock, and then I repainted it digitally using GIMP. All other assets were modelled by myself. I had also made a flat version of the game which had the script to light torches (detected when the player torch collided with the collider of the torch being lit), a player movement script (allowing movement with the keys W,A,S, and D), and a mouse look script (that allowed the camera to follow the position of the mouse).

In order to start the project, it was necessary to first decide what the aim and requirements of the experience would be. There is clearly a gap in the literature regarding learning and memory in VR so it was decided to focus on this by testing which multisensory effects would increase learning. Thus, the experience started by researching learning theories, interaction techniques and more about the cult of Mithras. After the initial research, the project was set to scale and additional features from the archaeological evidence such as the wooden support pillars and side altars were placed into the experience. Other objects were also placed in the experience based on my own artistic license such as bowls, coins (based on the coins of Victorinus from the archaeological record), and torches. While pottery and coins were found in the *mithraeum,* their exact use and location is unknown. In regards to the torches, it is likely that the Romans used some sort of fire to light the temple, as most *mithraea* were dark to simulate the cave, but these have not been excavated from the temple and it was solely placed in the experience in order to have the user complete a task. The Temple was exported from 3DS Max as an FBX file into Unity. Inside Unity, it was necessary to scale the file in order to fit the scene and some objects such as the pillars and torchers were created in Unity.

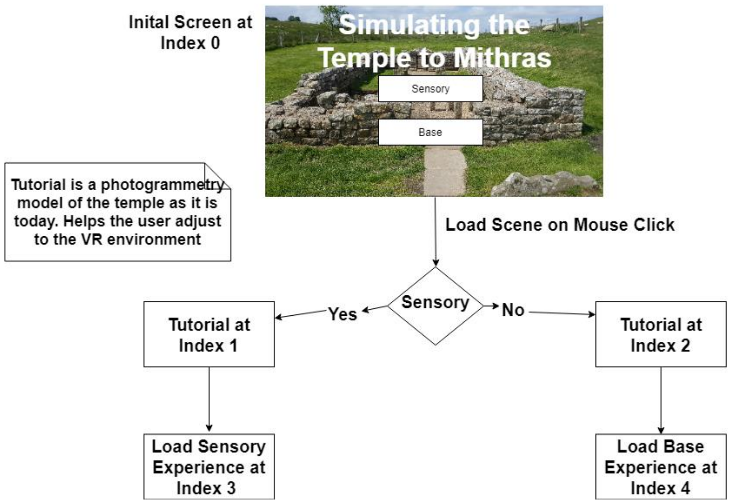

Figure 3: Planning the experience design. Design flow for changing between scenes

The experience changed multiple times during the course of the project as the scope narrowed. It was decided to focus on the efficacy of VR as a learning platform and if multisensory effects would have any impact on retention of information. Figure 3 shows the planning for the content and design flow. The user would start the executable program, choose to either do the Sensory or Base scene, complete a tutorial, and then start the experience. The tutorial was a photogrammetry model of how the site looks today, and the purpose was to get the participant used to the controls of the experience. However, neither the selection screens nor the tutorial made it to the final product stage. The final version of the project looked solely at learning over time without any multisensory effects. The tutorial scene was also dropped from the final product because the photogrammetry model was too uneven and was taking on the computer to run. Regardless of this, the requirements largely stayed the same.

All the requirements are detailed in Appendix C, but those related to the hardware and software are necessary to introduce here. The experiment was built to run on an Oculus Rift at room-scale. This means, that the user was free to walk around as long as they were within the confinement of the space. It was hoped to extend the experience to run on other headsets as well, and this was achieved by developing it to run on the Oculus Go standalone headset, but as of yet it is not possible to run on an HTC Vive, Windows Mixed Reality, or other HMD. The software used included Oculus SDK and Oculus Avatar, both found on the Oculus Developer site. Both of these were downloaded and imported into Unity. The most important piece of software used was the Virtual Reality Toolkit (VRTK) which is an open source toolkit that facilitates rapid prototyping and development of VR experiences. VRTK has many different C# scripts that can be dragged and dropped into any experience as well as manipulated in order to fit the experience, for example, as was done in this experiment, counting the number of objects grabbed.

Chapter 4 **Implementation**

4.1 Prototype I

Due to the prior work I did on the 3D modelling of the project, the environment, and basic interaction using VRTK was implemented within a week. On June 20th the prototype was tested by five colleagues to see what aspects needed refinement.

Summary of Responses for Prototype I (n = number of users that shared the response):

1. Make the torch not droppable, it is hard to pick up (n=2).
2. Too much information given at once (n=2).
3. Torch placement and ability to light needs to be fixed (n=1).
4. Objects need to be large enough to see and grab (n=3).
5. Let the user explore before giving information (n=5).
6. Visual aspects were received well, but the users were not paying attention to the information given and had a hard time figuring out how to teleport (n=3).

Based on the initial feedback, I remodeled various features inside the temple, fixed the colliders and placement of the torches, made the coins larger to grab, and decided to make a tutorial scene to allow participants to become acquainted with VR before sending them into the learning environment. The tutorial scene would also help show users how to grab objects and teleport around the scene. These additions were useful for the second prototype.

4.2 Prototype II

It was hoped to have an Arduino board running to test scent by the second prototype, however after not being able to get the required hardware it was not possible to build a scent machine to the Arduino. Therefore, the design of the experiment changed to just test learning over time. The second prototype was tested July 16 by giving it to two people online in the Research VR community (https://researchvr.podigee.io/) as well as two colleagues. At this point it was possible to teleport around the tutorial scene, and hear various audio clips about how to interact with the scene, but it was not possible to interact with any of the objects due to the uneven nature of the photogrammetry model.

Summary of Responses for Prototype II:

1. Tutorial is difficult to use and understand (n = 3).
2. Did not understand what was supposed to happen in the tutorial (n = 3).
3. Audio overlaps (n = 4).
4. On screen prompting/instruction would be useful (n = 2).
5. Environment is nice especially the lighting (n = 3).
6. Some clipping on edges (n = 1).
7. Torch was hard to grab at the start (n = 1).

Based on this feedback, I added more instructions in the onboarding process as well as the tutorial for the user to understand what their role is in the space. The audio issue will be discussed further below, but the initial solution was to design a queue to hold audio sources so they did not play over each other.

4.3 Final Product

Figure 4: Top Left: Temple in Unity. Top Right: Map of Temple shown to participants. Bottom Left: Interior of the Temple with directional lighting. Bottom Right: In experience image of the interior of the temple in VR.

The final experience started with the user being placed outside of the Mithraeum with the fort in the background and the voice of Mithras talking. The experience is dimly lit in order to feel more authentic to the ancient world. After Mithras instructs the participant to grab the torch, the torch is lit in order to see in the darkness. The player was to then light a total of eight torches in and outside of the *mithraeum*. As the user lit each torch they entered a sound zone and the voice of Mithras gave additional information about the temple and the religion. When the user passed the screen, they entered another sound zone which gave additional information about the content of the temple (Figure 4). It was attempted to use an audio queue to play the audio clips as the user moved freely about the space. However after unsuccessfully trying to implement this as the data structure of a queue and a list it was decided instead to create a box around the player as they entered each of the zones to contain them until the audio stopped playing.

4.4 Challenging pieces of the product

Throughout the development phase many hours have been spent working with Oculus SDK, Oculus Avatar SDK, Unity SDK, and VRTK. Rather than discussing all of the testing and development this section is dedicated to three examples: the Oculus SDK, Avatar, and VRTK, the Audio Queue and Player Controller, and the Arduino Uno.

4.4.1 Unity, Oculus SDK, Avatar, and VRTK

Unreal Engine 4 and Unity are the two main game engines that can be used to create VR experiences. It was decided to use Unity because it is programmable with C#. As C# is similar to Java it was fairly easy to pick up, however, Unity has many specific functions and ways to program and this was only found after spending time in the documentation. Some of the more difficult things to program included the understanding of game physics, the starting and stopping of the particle systems for the torches, the audio (detailed below), and understanding how colliders worked. In Unity, a collider is basically an invisible wall that can be used to make sure objects do not go through the collider or to act as a trigger that starts an event when an object does go through the collider. Both of these instances were used in this experience.

Originally, the experience was only going to built with the Oculus SDK and Avatar, however because the nature of VRTK is to foster rapid development it was quickly decided to use the toolkit. After installing VRTK, interactions such as grabbing objects and teleportation became much easier. Of course, this requires a thorough reading of VRTK documentation and understanding the sample scenes VRTK provides.

The biggest issue with VRTK was related to design choices for interactable objects. VRTK offers many options to grab objects. The choice for this design was between a fixed joint grab attach and a child of controller grab attach. The first acts more like the real world with good tracking of the grabbed object, and by breaking the grasp of the grabbed object if the object hits a collider in the scene. For example, if the user was holding the torch and they hit a wall, the torch would fall to the ground. It was initially decided to use this grab attach because it mirrored the real world, but it was hard to pick the torch up from the ground once it fell out of the users grasp. It was then decided that the torch should not be droppable, but upon implementing this feature, the torch would fly out of the user's hand if they ran into an object with a collider. It was therefore decided to use the child of controller grab attach which made the torch attached to the controller and not able to be dropped. This decision made the torch stay tracked with the user hand, however, the torch was able to go through colliders rather than stopping at them. The user was therefore able to swing the torch through the colliders in the scene (i.e. they were able to pass the torch through the wall, rather than having the wall stop the torch). While this did not quite match the real world, it did help people with not losing the torch and being able to complete the task more quickly and efficiently. Whilst watching people interact with the scene, an interesting point was that they generally followed the physics rules of the real world anyway. That is to say that when the user picked up the torch, they tried not to touch the end that was burning and they would hold the torch close to them when going through the experience, and stay away from the walls.

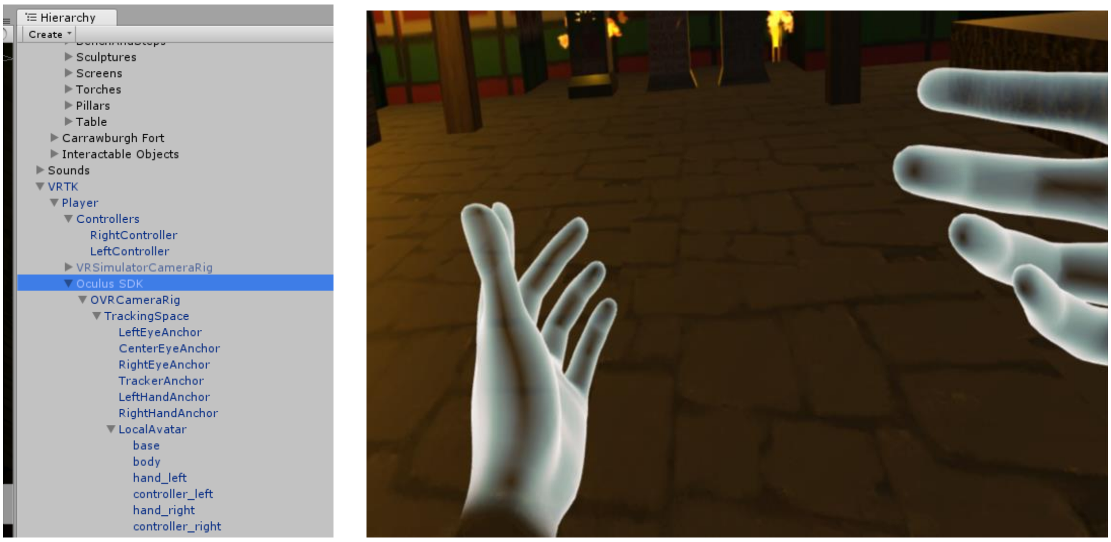

Figure 5: Left: Unity Element Hierarchy for Player. Right: Virtual Hands using Oculus Avatar

It was decided to give the user a sense of embodied presence by having responsive hands, that is to say that the user had virtual hands that would mimic the movements they made on the Oculus touch controllers. While VRTK has hand models, they still are not quite where they need to be in relation to visual fidelity and movement. Therefore it was necessary to use the Oculus avatar. Oculus Avatar is supported by VRTK, but using the Avatar hands are not fully supported. This was very evident when grabbing an interactable object, and the hand not being placed on the outside of the model. It was decided to make this trade off in order to have responsive virtual hands. However, there were other issues in implementing the Oculus Avatar to the experience. Mainly, this was due to the controllers not tracking properly. In order to fix this, it was necessary to first go to the OVRCameraRig prefab and set the tracking origin to the floor. After doing this, some performance was improved, but it still did not track the hands correctly. After trying various fixes, it was discovered that the LocalAvatar prefab must be placed inside the TrackingSpace of OVRCameraRig prefab (Figure 5). Following this, the tracking was much improved. In congruence with ancient history, only males were able to belong to the temple, and the initiates would have been naked and vulnerable when inside the temple. Due to this, it was decided to use a self-defined avatar to help the user understand their role in the space. However, there was not enough time to learn rigging and animation in order to make this work. Therefore, the avatar was the standard Oculus Avatar prefab, displayed in a first person viewpoint with a body. By doing this it was necessary to change the transform position and rotation of the avatar in order to make it look like it was the body of the user. Users responded positively to the use of the Oculus avatar, especially regarding the hands which respond very well to the movements on the Oculus touch controllers.

4.4.2 Audio Queue/Player Controller

The Audio Queue was the most complicated piece of programming attempted, and was ultimately discarded for the player controller which had a better interaction design. The idea behind the audio queue was to have the user enter various 'sound zones' which were areas that held an audio source that would be placed in a queue once the user entered the collider of the zone. This way, if the user entered a different sound zone while audio was playing, the audio would not overlap. While the queue seemed to be the best data structure to use, due to the first in first out nature, it was easier to implement as a list. There were quite a few iterations of this. The best way seemed to use a two class implementation. The first class tracked the user and got the audio from the zone and added it to the queue once a collision was detected between the user and the zone. The second class handled the functionality of the queue, the enqueuing and dequeuing of audio sources as well as playing the audio in the queue if the size of the queue was greater than 0. The second implementation used a single class to track the player, add the audio source to a list, and play the audio. The second implementation was working, but the audio would keep play the entirety of the list, rather than one audio clip at a time. After trying these data structures for some time and not getting it to work, it was decided to find a different way of playing the audio.

Following the interaction design of video game tutorials, it seemed clear that the better design, and the easier method of programming, was to turn on colliders once the god voice started speaking to keep the user inside the zone. This gave the user some freedom to move around, but it kept them in the zone which provided the information that was specific to that zone. This was implemented in the PlayerController.cs script. The sole purpose of this class was to turn the colliders on once the user entered the sound zone so that the user was unable to move out of the specified space. Another script, TestPlayersControl.cs was created to try and clean the code up by using arrays for the colliders, but this did not work.

4.4.3 Arduino

The original design of the experiment was to test users learning in VR with and without scent. It was thought to use IFTTT in order to make the connection to turn on a scent machine, however, I wanted to use an Arduino and a fan, like others have done (Stu Eve's Dead Man's Nose, and the University of Reading in their multisensory interpretation of Roman Silchester). An Arduino is an open-source microprocessor, in order to control the Arduino, a program is written in Arduino programming language. All Arduino sketches have a basic form containing setup and loop functions. All sketches must have a setup() and loop() even if they are not used. Setup is called at the start of the sketch and is used for initializing variables and setting the pin mode (the pin is either for input or output). The loop function keeps getting called while the sketch is running. In order to add a scent, it was decided to connect an the Arduino in Unity, it was necessary to first change the API Compatibility Level from .NET 2.0 subset to .NET 2.0 in Player Settings. Then learn how to program the Arduino board by doing simple scripts such as turning the light on and off using the setup() and loop(). For the scent addition, all that was necessary to do was turn the fan on once the Arduino was connected to Unity. Therefore, the next step in development was to create a Unity script that would register the Arduino board. It was decided to create a count down when the board was connected and running to try and get it printing to the unity console. After this, I figured out how to connect the Arduino board to Unity using the System.IO.Ports import. This involved writing an Arduino sketch and uploading it to the board. This sketch was created with the Arduino Web Editor, and uploaded to the Arduino Uno via a USB cable.

Since the design was to turn a fan on once the experience started, a button was declared to connect the fan to on the Arduino board. For testing the connection to Unity, once the experience started, the Arduino would run on a loop and print a count to the console while connected. This was implemented, but because it was not possible to obtain the hardware necessary to add the fan and scent, it was not used in the final product.

Chapter 5 Evaluation & Analysis

5.1 Experiment Design

The experiment was a pseudo-longitudinal study to look at user's gathering and retention of information over a period of 10 days. There were a total of 12 participants ranging in age from 18-39. The user came into the study, were given the information sheet and consent form and then completed a pre-experience questionnaire (PRQ) and learning questionnaire (LQ). Borrowing concepts from E-learning theory, the participant was then given a description of what they were about to experience and what would happen once they were inside the experiment. The participant then put on the HMD and was given time to see how their hands reacted inside the Oculus Home VE, after they were placed into the VE for the experiment. The interactions in the experiment were that the user was able to walk around the temple and light the torches. Each time they hit a sound zone, the god voice would give them information. After lighting the eight torches in the temple, the participant was given the opportunity to explore the temple and fort landscape, or to come directly out of the experience. Once they finished, the participants completed a post-experience questionnaire (PQ), and the LQ. After ten days, the participants were once again emailed the LQ and after completing were discharged from the study.

The independent variable was the time at which the LQ was distributed with levels of pre-experience (Level 1), post-experience (Level 2), and ten days after (Level 3). The dependent variable was participants score on the questionnaire. Of course, a questionnaire is a subjective measurement so the study will have more external validity, but the internal validity is limited. The study also had various confounding variables such as the primary language of participants, knowledge of ancient history, previous VR experience the participant had, personal learning style, and the quality of visual environment. Another problem that occurred was computer performance. As no computer was supplied for the experiment, it was necessary to use my own which has been having performance issue which caused dropped frame rates and lag time while running the VR experiment.

5.2 Quantitative Results LQ:

The LQ had a total of 7 questions that were able to be validated and three questions that were either open response or asked if the user had conducted any research on the content of the experience (Appendix B).

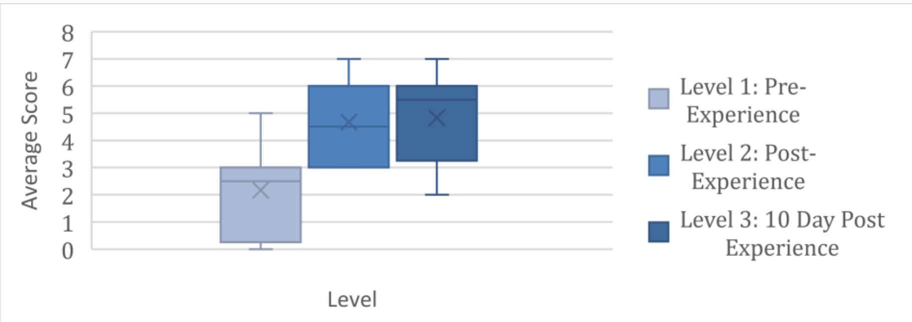

Table 1: Average score of all participants on the LQ across the three levels.

The initial analysis of data looked at the mean score of correct answers on each of the learning questionnaires. Level 1 had a mean of 2.17 and a SD of 1.64. Level 2 had a mean of 4.67 correct answers with a SD of 1.50. Level 3 had an average of 4.83 with a SD of 1.80. These results indicate that the design of the experience and using VR was helpful in learning for some, but not for others. After performing this analysis, it was necessary to perform a repeated measures ANOVA test.

The ANOVA data showed a significant difference between the three conditions, $F(2, 22) = 17.44$, $p < 0.001$. The post-hoc comparisons, corrected using the Bonferroni method, showed that there was a significant difference ($p = 0.003$) between the Level 1 and Level 2. Similarly, there was a significant difference ($p = 0.003$) between Level 1 and Level 3. However, there was no significant difference between Level 2 and Level 3. This suggests that people remembered the content.

5.3 Quantitative Results PQ:

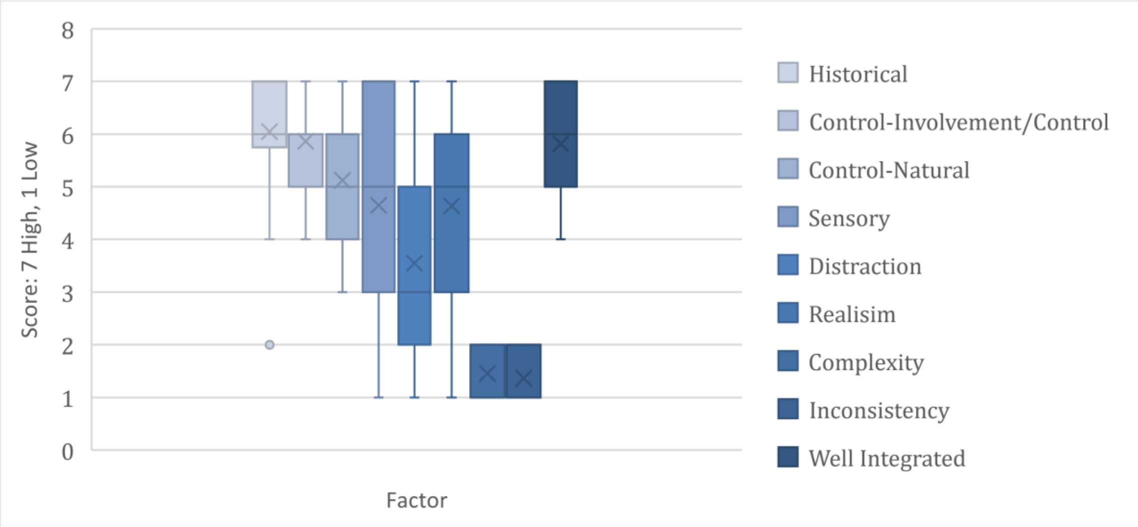

Table 2: PQ Average Response Score: 1 is low, 7 is high.

The PQ consisted of 21 questions that can be roughly divided into 9 different factors (Table 2 and Appendix B). The questionnaire modified Witmer and Singer's Presence Questionnaire as well as the System Usability Scale (SUS). The factors tested were: control factors-natural, control factors-involvement/control, sensory, distraction, realism, complexity, inconsistency, and integration. The historical factor was added in to ask the user if the experience seemed historically accurate and authentic. Two other questions were added to ask the user if they thought they would use the experience in a classroom, and the other if they would use the experience at a museum or heritage site. The most interesting results from this study were related to the sensory, SUS, and distraction factors.

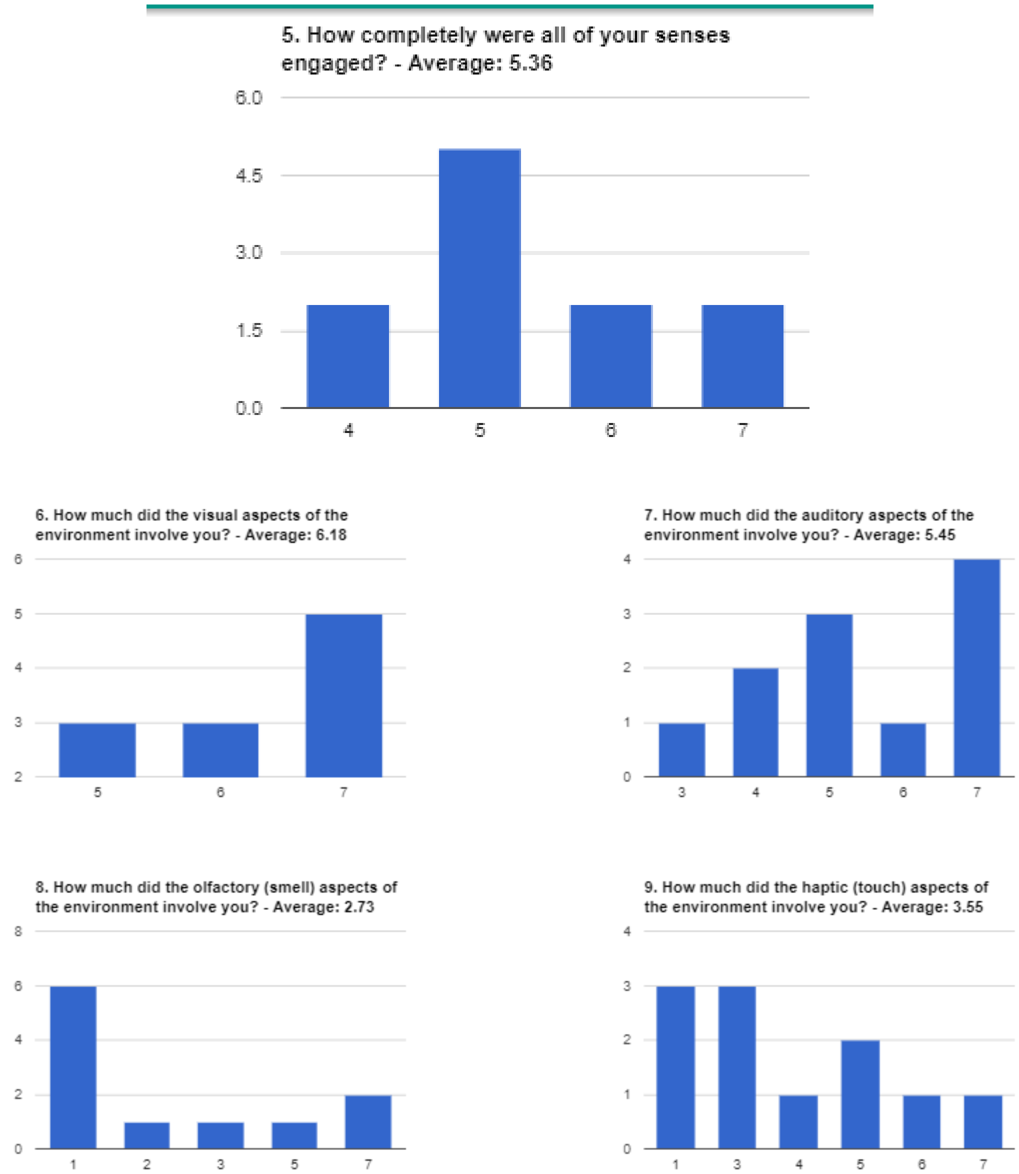

Table 3: Distribution of answers relating to sensory factor questions.

The sensory factors had a wide distribution of data points (Table 3, avg 4.65, SD: 2.1). The visual aspects scored the best, with an average of 6.18, whereas the olfactory aspects scored a 2.73 and the haptic 3.55, but these had a wide distribution of data points. There were no scents used in the experience, and there was one haptic interaction when the user picked up their torch.

The distraction factors only scored a 3.55 with a SD of 1.79 which suggests that there was a major difference between participants. While the physical room was always the same, there were extraneous factors that were happening outside of the experiment (such as construction) that may have influenced this.

The experience was rated as having little complexity (avg 1.45, SD: 0.52) and inconsistency (avg 1.36, SD: 0.5) and well-integrated (avg 5.82, SD: 0.94). This was positive as much detail and attention went in to the experience to make sure it was easy to learn how to use even for those who have never used VR before.

5.4 Qualitative Results

The qualitative results gave good insights and relevant information about the experiment. This included three participants thinking that the torch lighting was part of the *mithraic* ritual, and five recalling visual or spatial information. These suggest that in experiences related to the past, extreme care must be taken when designing the experience. It seems that more information is taken in via the eyes and interactions, rather than the speaking. It will therefore be important, to make sure that the spatial information is correct, or is clearly defined where uncertainty lies.

Four people commented on the location of the temple outside the fort. Five people remembered information supplied by the voice of Mithras about the initiation rituals, such as being burnt by torches, buried in a pit, and cut by a sword. Eight people recalled sensory information about the site including the audio (roar of the torches and god voice) and the visual information such as the statues of Cautes and Cautopates, altars to Mithras, and the cult statue. Two participants commented on the environmental effects of lighting and interaction with coins and bowls.

Chapter 6 **Discussion and Conclusion**

This experiment suggests that VR can be used to learn about the past and that people will retain the information given. However, this does not mean that VR should replace current learning methods, especially until further research can be conducted related to learning and interactions. The PRQ showed that seven of the twelve participants were visual learners, three were verbal, and two were physical/kinesthetic learners. This could also be a contributing fact to the significant result of the data. A VR VE is a highly spatial environment and those that learn visually have plenty of opportunities to see and explore an environment to gain information. Those that learn best verbally were slightly disadvantaged, as there was no written text. The addition of text is something to look into for further research as comments from the PQ also mentioned that reading text may help their learning. However, text in VR is not optimal due to the resolution of the displays. Many HMDs have a setting to adjust the lenses for user's IPD (interpupillary distance) which allows the display to become clearer.

The interaction design of the experience is extremely important as the experiment must be historically accurate, well presented, and fit expectations of viewers. As is shown in reviews of historical VR models on the Oculus Store, users want interaction, high quality visuals, and free locomotion. Supplying these can allow the user to move around as they want and explore the environment. This type of interaction is beneficial following the key aspect of experiential learning theory stating that experience is the best teacher. This suggests that allowing the user to explore the environment, pick up objects, make their own conclusions will help the user learn. However, this applies more to users that have experience in VR than it does to new users. In the experiment nine out of the twelve participants have used a VR HMD less than three times. Also when looking at the LQ and PQ in combination, it does seem that a VR experience can be effective for learning even if there is a large variance between subjects regarding multisensory, realism, and distraction factors. The experience was rated as easy to use and easy to control, and having well integrated features even with those who have limited VR experience. It bears mentioning that if a person has never tried VR they need time to adjust to having the HMD on, to see how their hands in VR, and get used to the way they can interact with the environment. While this does not take long, the additional time must be taken into consideration when designing experiences. Upon observation, those who have never used VR or have used it only once had more trouble understanding how the teleportation mechanic worked and how to grab the objects. Those who felt comfortable in VR were able to catch on very quickly to complete the experiment. Two participants thought that the torch lighting task was a part of the Mithraic ritual and this brought up an important point of how to display the past.

Once people see the VE and interact inside of it, they are more likely to believe that was what the past was like. Extra care must be taken in order to let users know that what aspects of the experience were based on interpretation. This could include using special effects to highlight objects that were not found in the archaeological record, or have some information point that will give more information. However, in doing this, it can break the immersion or not be coherent. One possible solution to this would be to show multiple versions of a site, show change over time, and give information points. This will allow the user to understand that sites are living and constantly changing. The user could have control in selecting which interpretation they want to see and become more involved. If the user wishes to learn more, they can read the information points. This may also help with learning.

In the experiment, all but two participants answered more questions correctly from the pre-experience to post-experience LQ. This indicates that the experience did convey the information that it needed to and that the information was retained. Interestingly, eight of the twelve participants matched their score between the post-experience LQ and ten day post-experience LQ. This suggests that what was learned in VR during the experiment still was remembered ten days later. Having another test after a month would be helpful to see if the same would be true. From participant information, some of the immersive effects of the experience, such as the multisensory effects, were really helpful for involving them in the experience. The sensory data was varied across all participants and had the highest SD of any factor. Whilst the visual aspects were all grouped between scores of 5-7, the haptic, auditory, and olfactory questions were widely distributed. This brings about the limitations of the study and need for further research.

6.1 Limitations and Further Research

One of the limitations of this project was the lack of polished style. Without comparing the scents in a proper, AAA game style environment, it is difficult to make any assertion that this is viable at all. Content cannot be separated from the VR experience, and further research must look into how this effects the experience (Chertoff et al. 2008; Chertoff et al. 2010; Skarbez et al. 2017).

Another limitation was the visual fidelity, while the average response to how involving the visuals were was a 6.18, testing against higher quality experiences is necessary. Everything was designed and developed by myself, a person with less than a year of experience in 3D modelling, texturing, and Unity development. This may have had an effect on presence.

A third limitation is the subjective questionnaires. It is difficult to quantify level of presence after the experience has finished and the data is not quite as meaningful, because an involvement rate of 2 is not meaningful. Slater has suggested that the user shout 'Now' when they do not feel present in the VE (2000). However, this is distracting, and can aide in not being present in the VE.

Finally, experience may not be a good way to learn for all people, and should be treated as a complement to traditional methods of learning. For example people that learn best by reading text, may not learn best from this experience. However, the VR experience does give participants visual, auditory, and physical options but with unequal advantages related to learning. The experience favours those that have a verbal learning style since the god voice gives the information.

Much more needs to be done on this project to make it viable for use in a heritage site or general applications. It should also be tested inside a museum setting because the lab environment does not control for sounds of a crowd. It is also needed to research more about the design and content of the experience and visual fidelity. I do not possess great 3D modelling skills, but would a better model (such as that done by Soluis Heritage) provide better results? Levels of the god voice-Mithras was portrayed by someone from Northern Ireland, but should it be someone with an accent that represents that from Hadrian's Wall, or Rome, Persia, or an English accent (as is often portrayed in films)?

Further research would benefit as follows:

1. Determining if there is an increase in participant learning when using VR compared to tradition learning methods and video.
2. Determining the value (if there is any) in adding multisensory effects.
3. Determining if interactivity matters. Will the user learn as well with 360 images and videos, or does interactivity and free locomotion matter?
4. Looking at the effect of high quality visuals over low quality.
5. Testing various interaction designs to see what is the most suitable for these experiences.
6. Testing the experience in a museum or heritage setting, where there will be extra distractions.
7. Testing if the user can learn without a voice over. Will a user be able to learn about a site by walking around and examining objects and receiving cues from the environment, much like happens in everyday life?

6.2 Challenges

The challenges of creating a VR experience are many, however, a few are important to note. The first is that PC VR requires computers that are robust and have a powerful graphics card. Secondly, graphics must be respond to the head rotation within 20 milliseconds for a smooth performance. Any longer can induce nausea. Thirdly, it is very important to understand how to optimize performance to run VR. This includes optimizing textures, models, and interactions. However, due to the limited amount of time for this project, these optimization techniques were not put into practice. Had there been more time to look at them, perhaps the performance would have been improved. Another solution to this, may have been using NVIDIA VRWorks which would have helped with rendering.

6.3 Conclusion

The research question and answers addressed in this paper were as follows:

- Is VR an effective way to learn about the ancient world?
  - Yes, VR does seem like it could be a valid way to learn about the ancient world as participants appeared to retain the information that was given to them ten days after the experiment.
- Could this learning be attributed to the feeling of presence in VR?
  - While users did have relatively high responses to levels of presence, there were too much variations to make any conclusion. More research is needed to test if participants using VR retain the information more than those watching a video or reading a text.
- Does the user retain the information they learnt over time?
  - This experiment tested if the user retained the information for 10 days, and it does appear that they do.

Chapter 7 **References**

Adkins, G., Holmes, N., Mills, N. (2013) *The Hadrian's Wall Interpretation Framework: Audience Research.* In N. Mills (Ed.) *Presenting the Romans: Interpreting the4 Frontiers of the Roman Empire World Heritage Site.* Woodbridge: Boydell & Brewer Pp. 157-170.

Aggleton, J.P., Waskett, L. (1999) The Ability of Odours to Serve as State-Dependent Cues for Real-World Memorie: Can Viking Smells Aid the Recall of Viking Experiences? *British Journal of Psychology, 90,* 1-7.

Bailey, J., Bailenson, J.N., Won A.S., Flora, J., Armel, K.C. (2012) Presence and Memory: Immersive Virtual Reality Effects on Cued Recall. *Proceedings of the International Society for Presence Research* October 24-26, Philadelphia, Pennsylvania.

Caesar. (1914). *Civil War.* Trans. A.G. Peskett. Cambridge, MA: Harvard University Press

Chertoff, D.B., S.L. Schatz, R. McDaniel, & C.A. Bowers. (2008). Improving Presence Theory Through Experiential Design. *Presence 17(4),* 405-413.

Chertoff, D.B., B. Goldiez, & J.J. LaViola Jr. (2010). Virtual Experience Test: A Virtual Enviornment Evaluation Questionnaire. *IEEE Virtual Reality.*

Dinh, H.Q., N. Walker, C. Song, A. Kobayashi, & L.F. Hodges. (1999). Evaluating the Importance of Multi-Sensory Input on Memory and the Sense of Presence in Virtual Environemnts. *Proceedings IEEE Virtual Reality* https://doi.org/10.1109/VR.1999.756955

Fabola, A. & A. Miller. (2016). Virtual Reality for Early Education: A Study. In C. Alison, L. Morgado, J. Pirker, D. Beck, J. Richter & C. Gutl (Eds.) *Immersive Learning Research Network: Second International Conference* iLRN 2016 Santa Barbara, CA: USA, June 27-July 1, 2016 Proceedings. Communicaations in Computer and Information Science, Vol 621. Cham: Springer. Pp 59-72

Greany, S. (2013). Reconstruction Drawings: Illustrating the Evidence. In N. Mills (Ed.) *Presenting the Romans: Interpreting the4 Frontiers of the Roman Empire World Heritage Site.* Woodbridge: Boydell & Brewer Pp. 31-40.

Herz, R., Schankler, C., Beland S. (2004). Olfaction, Emotion and Associative Learning: Effects on Motivated Behavior. *Motivation and Emotion 28(4),* 363-383.

Ijsselsteijn, W.A., de Kort, Y.A.W., & Haans, A. (2006). Is This *My* Hand I See Before Me? The Rubber Hand Illusion in Reality, Virtual Reality, and Mixed Reality. *Presence, 15(4),* 455-464. https://doi.org/10.1162/pres.15.4.455.

Jang, S., Vitale, J.M., Jyung, R. W., Black, J. B. (2017) Direct Manipulation is Better than Passive Viewing for Learning Anatomy in a Three-Dimensional Virtual Reality Enviornment. *Computers & Education, 106,* 150-165.

Kolb, D.A., R.E. Boyatzis, & C. Mainemelis. (2001) Experiential Learning Theory: Previous Research and New Directions. In R.J. Sternberg and L.F Zhang (Eds.) *Perspectives on Thinking, Learning, and Cognitive Styles.* Pp.227- London: Routledge.

Lanjouw, Tijm. (2014) Discussing the Obvious or Defending the Contested: Why are we still discussing the 'scientific value' of 3D applications in archaeology?. In H. Kamermans, W. de Neef, C. Piccoli, A.G. Posluschny, and R. Scopigno (Eds.), *The Three Dimensions of Archaeology. Proceedings of the XVII UISPP World Congress 1-7 September 2014 Burgos, Spain.* Pp. 1-12.

Martin, L.H. (2015). *The Mind of Mithraists: Historical and Cognitive Studies in the Roman Cult of Mithras.* London: Bloomsbury Academic.

Mayer, R.E. (2003). Elements of a Science of E-Learning. *J. Educational Computing Research, 29(3),* 297-313.

Mills, N. (2013). Introduction: Presenting the Romans—Issues and Approaches to Interpretation. In N. Mills (Ed.) *Presenting the Romans: Interpreting the4 Frontiers of the Roman Empire World Heritage Site.* Woodbridge: Boydell & Brewer Pp. 1-10.

Plato. (2008). *The Republic.* Trans. R. Waterfield. Oxford: Oxford University Press.

Pliny. (1938). *Natural History.* Trans. W.H.S. Jones & A.C. Andrews. Cambridge, MA: Harvard University Press.

Price, S., Rogers, Y., Scaife, M., Stanton, D., Neale, H. (2003). Using 'Tangibles' to Promote Novel Forms of Playful Learning. *Interacting with Computers, 15,* 169-185.

Richmond, I.A. & J.P. Gillam. (1951). The Temple of Mithras at Carrawburgh. *Archaeologia Aeliana, 4(29),* 1-92.

Seneca. (1971). *Naturales Quaestiones I.* Translated by T.H. Corcoran. Cambridge, MA: Harvard University Press.

Skarbez, R., F.P. Brooks Jr., & M.C. Whitton. (2017a).Immersion and Coherence in a Visual Cliff Environment. *IEEE Virtual Reality,* 397-398.

Skarbez, R., F.P. Brooks Jr., & M.C. Whitton. (2017b). A Survey of Presence and Related Concepts. *ACM Computer Survey, 50(6),* 96:1-39.

Slater, M. & Steed, A. (2000). A Virtual Presence Counter. *Presence: Teleoperators and Virtual Environments, 9(5),* 413-434. https://doi.org/10.1162/105474600566925.

Slater, M. (2009). Place Illusion and Plausibility Can Lead to Realistic Behaviour in Immersive Virtual Environments. *Philosophical Transactions of the Royal Society, 364,* 3549-3557.

Toner, J. (2014). Introduction: Sensing the Ancient Past. In J. Toner (Ed.), *A Cultural History of the Senses in Antiquity* (pp. 1-22). London: Bloomsbury Publishing Plc.

Witmer, B.G., Singer, M.J. (1998). Measuring Presence in Virtual Environments: A Presence Questionnaire. *Presence, 7(3),* 225-240. https://doi.org/10.1162/105474698565686.

Appendix A Consent Form & Information Sheet

University of Glasgow | School of Computing Science

Participant Consent Form

The aim of this study is to evaluate the effectiveness of Virtual Reality (VR) as a tool to increase learning and memory. The experiment will take approximately 20 minutes to complete.

Upon signing up for the experiment you will be asked to complete a pre-experience questionnaire. You will be ineligible for the study if you fall in any of the following categories as per the manufacturer's instruction:

* Pregnant, Elderly, or under the age of 18
* A history of epileptic seizures, strokes, or photosensitivity
* Suffer from visual disorders
* Have suffered brain injury
* Suffer from a heart condition or other serious medical condition

Before putting on the VR headset you will be asked to complete a learning questionnaire. You will then put on the headset and go into the experience. At the end of the experiment, you will be asked to complete the learning questionnaire again. Two weeks after participating in the experiment, you will be asked to complete the learning questionnaire one final time.

All data will be anonymous. No personal participant information will be stored. Data will be deleted once the dissertation is finished on September 9, 2018. All email communication will be deleted at this time as well.

Please note that you may withdraw from the experiment at anytime without prejudice, and any data already recorded will be discarded.

If you have any further questions regarding this experiment, please contact:

Researcher: Deborah Mayers, 2067887m@student.gla.ac.uk

Supervisor: Stephen Brewster, stephen.brewster@glasgow.ac.uk

Statement of Consent

The purpose of this study, procedures to be followed, and risks have been explained to me. I have been allowed to ask questions, and my questions have been answered to my satisfaction. I have been told whom to contact if I have questions, to discuss problems, concerns, or suggestions related to the research, or to obtain information or offer input about the research. I have read this consent form and agree to be in this study, with the understanding that I may withdraw at any time. I have been told that I will be given a signed and dated copy of this consent form.

Name: ______________________________ Date: ____________________

Signature: ______________________________ Time: ____________________

Information Sheet

Introduction

You are being asked to take part in a research study, which aims to evaluate the effectiveness of multisensory effects in Virtual Reality (VR). Research studies are voluntary and include only people who choose to take part. Please read this consent form carefully and take your time making your decision. As the researcher discusses this consent form with you, please ask for an explanation if you do not clearly understand the information being presented. The nature of this study, risks, discomforts, and other important information about the study are listed below.

Deborah Mayers, will conduct this study as part of her Master's dissertation. Any information collected during this study will be anonymised and presented in this dissertation.

Why is This Study Being Done?

The purpose of this study is to evaluate the degree to which multisensory effects increase or decrease user engagement in a virtual reality experience.

What is Involved in This Study?

If you agree to be in this study, you will be asked to sign and date this consent form. You will put on a virtual reality head mounted display and begin the experience. At the start of the experiment you will be asked to become familiar with the VR head mounted display by using the controls in a tutorial scene. The researcher will take note of behaviour presented during the experiment (I.e. extreme frustration or amazement). If at any time, it appears that you are very uncomfortable the researcher may ask if you would like to leave the experiment. At any point during this study if you feel sick or uncomfortable you may take of the HMD and continue again, or leave the study. After the experience is over, you will be asked to complete a questionnaire related to the experience.

Who is ineligible for this study?

If you fall into any of the categories in the risks section or are prone to epileptic seizures, you will not be eligible for this study as detailed in the risk section below. Additionally, participants must be 18 years or older.

How Long Will This Study Take?

The experience lasts approximately 20 minutes.

What are the Risks of the Study?

The following risks can be related to the use of virtual reality. As a precaution, anyone with a history of epilepsy is discouraged in taking part of this study because the use of VR may induce a seizure. We will do our best to reduce the risk of running into any objects by stopping you if you are about to hit a wall.

- Dizziness
- Nausea
- Seizures
- Bumping into objects

If at any time you wish to stop taking part in this study due to any of these factors, please just say so and we will stop.

Under the recommendations of Oculus (manufacturer of the VR headset) anyone in the following categories should not use VR:

* Pregnant, Elderly, or under the age of 18

* A history of epileptic seizures, strokes, or photosensitivity

* Suffer from visual disorders

* Have suffered brain injury

* Suffer from a heart condition or other serious medical condition

Will my Information be Kept Confidential?

The University of Glasgow makes the effort to keep personally identifiable information collected about you confidential. The consent form that has your name will be stored in a secure location and will be shredded after the study is over on September 9, 2018.

As part of this study, Miss Mayers will not use any identifiable data in her dissertation. This will be done by assigning a unique code word to each participant and this data will be used to analyse and share the results.

Research Related Injuries

If you are in need of immediate medical care as a result of your participation in this research study we will call 999 on your behalf. However, there is no commitment by the University of Glasgow or the researcher to provide monetary compensation to you in event of a study-related injury.

Declining Participation or Withdrawing from the Study

You may choose not to be in the study, or alternatively, if you have agreed to be in the study, you may withdraw from the study at any time. If you withdraw from the study, no additional data will be tracked and any data obtained will be discarded.

Whom do I contact if I Have Questions or Problems?

For questions about the study contact Deborah Mayers at 2067887m@student.gla.ac.uk.

Appendix B Questionnaires

Learning:

1. Have you done any research on the Ancient Romans, Carrawburgh, or the temple and religion?
2. What was the name of the god at the temple?
3. What was the name of the man that dedicated this altar?
4. What was the Roman (Latin) name of the fort where the temple was located?
5. What type of incense was burned at the temple?
6. “What was involved in the initiation ritual? (i.e. what did initiates do? What trials did they go through?)
7. What was displayed on the cult statue?
8. What was the highest rank in the cult?
9. What troop was stationed at Carrawburgh?
10. Is there anything else you remember from the experience? This could be visual environment, auditory, what you felt/experienced, etc.

Pre-Experience:

1. I do not fall into one of the following categories: Pregnant, Elderly, or under the age of 18, a history of epileptic seizures, strokes, or photosensitivity, suffer from visual disorders, have suffered brain injury, suffer from a heart condition or other serious medical condition.
2. How often do you use VR (virtual reality) headsets?
3. How much knowledge do you have about the Ancient Romans?
4. Have you heard of Hadrian's Wall before?
5. Have you heard of Carrawburgh or Brocolitia before?
6. Have you heard of the cult of Mithras?
7. What is your learning style?
8. How do you identify your gender?
9. Age
10. Role

Post-Experience:

1. Did the content seem historically accurate or authentic?
2. How much were you able to control events?
3. How responsive was the environment to the actions you initiated (or performed?)
4. How natural did your interactions with the environment seem
5. How completely were all of your senses engaged?
6. How much did the visual aspects of the environment involve you?
7. How much did the auditory aspects of the environment involve you?
8. How much did the olfactory (smell) aspects of the environment involve you?
9. How much did the haptic (touch) aspects of the environment involve you?
10. How natural was the mechanism which controlled movement through the environment?
11. How aware were you of events occurring in the real world around you?
12. How aware were you of your display and control devices?
13. How inconsistent or disconnected was the information coming from your various senses?
14. How much did your experiences in the virtual environment seem consistent with your real world experiences?
15. How well could you manipulate or move objects in the virtual environment?
16. Would you use this system in a classroom?
17. Would you use this system in a museum or heritage site?
18. I found the system unnecessarily complex to use
19. I found the functions of the system to be well integrated
20. I found there was too much inconsistency in this system
21. The content presented seemed valid and historically correct

Appendix C Moscow Report

For this dissertation, a Trello board was used to document the work done on the project. This can be found at: https://trello.com/b/Lnjgx3Ho/simulating-the-temple-of-mithras.

Gathering requirements was fairly simple as this was a self-defined project and will be used as I continue the mithraeum project for deployment onto Steam or Oculus Home.

7.1.2 Functional Requirements

Must Have

1. Locomotion.
2. Object Interaction.
3. Torch Lighting.
4. Load experience (either sensory or base) based on mouse click.
5. The user must be able to exit the experience at any time.
6. Trigger scent in particular spot of the scene. (Not implemented, as the sensory feedback was taken out of the experiment).

Could Have

1. The controller (avatar hand) becomes the object when picked up. (Not implemented).
2. Press button on VR UI to load experience after tutorial scene.

Should Have

1. User hands are unable to go through objects such as walls.

Would Like To Have

1. Trigger object sound on object pick up.
2. Trigger object sound when object is set down.
3. Trigger haptics on object pick up.
4. Custom avatar to be historically accurate.
5. Body animation and tracking.

7.1.3 Non-Functional Requirements

Must Have

1. The model must be to-scale.
2. The model must remain true to the archaeological record.
3. Documentation must be provided for anything that was created with artistic license.
4. Must work with a Windows 10 PC that has VR capability.
5. Must work with Oculus Rift and Touch Controllers.
6. The experience should implement VRTK, Oculus Avatar (for a user to have embodied presence), and Oculus SDK.
7. The experience must be downloadable to run on a computer that does not have Unity, but can run an Oculus.
8. Textures, sounds, and models must be optimized.
9. The experience must be easy to learn (i.e. locomotion and grab interactions).
10. The experience must be to current VR standards (90 fps refresh rate, less than 20ms lag).
11. Audio must be spatially mixed.
12. The experience must be room-scale so the user can walk around or teleport as needed.
13. The experience must be easy to reboot and restart.
14. The entirety of the product must be grounded in academic research.

Would Like To Have

1. Experience can work with other VR HMDs.
2. Experience should be released on Steam.
3. Optimize the experience to work at 90fps on a NVIDA 960 GPU.