Impacts of Augmented Reality upon Memory Retention within History and Heritage Education

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Abstract

Technological innovation in the field of Augmented Reality has permitted for new opportunities within the field of education, allowing for exciting and revolutionary ways for learners to visualise and engage with learning content that have previously been difficult, expensive, logistically implausible, or even impossible. Despite this, there has been limited research into the efficacy of this technology for long-term memory retention and exploration of how Augmented Reality-based learning compares against traditional education mediums, a factor that is especially important when considering the potential costs of developing and implementing such systems. There is also little research into how much adult audiences can learn from such experiences, with most existing research targeting children of school ages instead. This study addresses this gap by investigating the use of Augmented Reality to deploy learning environments utilising different hardware mediums and different locations. to identify if they facilitate learning more effectively for long-term memory development for adult learners when compared against a traditional learning experience. Using a Microsoft HoloLens and a Leap Motion controller, a new method of Augmented Reality interactions was implemented to allow for learners to engage with virtual content along with a mobile phone application variant of the same learning experience. Participants were divided into four groups, each being tested with a different implementation of the technology and at different locations, who were then subjected to tests both immediately after their experiment and again three months later. Results found that learners retained the most information when learning through a traditional classroom lecture, although the use of AR did result in a slower rate of knowledge decay between the two testing intervals which suggests that although more is learned without the technology, more is retained with it. This directly contradicts prior research into Augmented Reality for memory retention, which suggests that previous research may not be applicable to adult audiences.

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List of Publications

The following publications are listed chronologically in order of date.

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Challenor, J. (2023). Fortnite's new in-game Holocaust museum shows us a virtual future for education. [Online]. 2023. The Conversation. Available from: https://theconversation.com/fortnites-new-in-game-holocaust-museum-shows-us-a-virtual-future-for-education-215500. [Accessed: 11 January 2024].

Challenor, J., MacCallum-Stewart, E. & Rimmer, B. (2025). A Review of Accessibility and Sustainability in Augmented Reality Tabletop Gaming Experiences. Multimedia 2025, Vol. 1, Page 7. [Online]. 1 (2). p.p. 7. Available from: https://www.mdpi.com/3042-6308/1/2/7/htm. [Accessed: 14 February 2026].

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List of Abbreviations and Nomenclature

AR: Augmented Reality

ANOVA: Analysis of Variance

HMD: Head Mounted Device

MR: Mixed Reality

VR: Virtual Reality

PNS: Project North Star

FOV: Field of View

TEL: Technology-Enhanced Learning

1. Introduction

1.1. Background and Rationale

Augmented Reality (Furthermore referred to as AR) is a technology that has been implemented in countless areas and environments since its original inception in 1992 (Poetker, 2019). Even prior to the official invention of the technology by Armstrong Laboratories, other systems and inventions anticipated the concept of overlaying virtual data with the real-world, dating back as far as Lyman Frank Baum predicting the technology in his 1901 novel "The Master Key" (L Frank Baum, 1901). Since then, the technology has been fully implemented for areas such entertainment(Jang & Liu, 2020), education (Chun Lam et al., 2020), military (Bach, 2021), heritage (Kyriakou & Hermon, 2019) and even in the emergency services for purposes such as firefighting (Bhattarai et al., 2020). This has been exacerbated by the process of Accelerated Change (Arjen E.J. Wals & Peter Blaze Corcoran, 2012) resulting in AR applications/experiences no longer requiring bespoke hardware. Instead, these applications can be efficiently deployed to existing consumer-grade hardware, such as smart phones, tablets, or even other forms of consumer-grade wearable computers such as mixed reality headsets or the upcoming Apple Vision Pro.

Consequently, new opportunities are available for deploying AR technology in environments that stand to benefit greatly from the potential it offers. The list of these would be substantial, however among the entries, the field of education is a very prominent potential candidate due to the new ways it can be used to deliver educational content to learners or change the way that they interact with their learning. It is for this reason that AR has been chosen as the technological medium for this project.

1.2. What is Augmented Reality?

The British Computer Society defines AR as "combining the digital world with the physical one and therefore augmenting the real-world experience. It brings the real and virtual worlds closer together by adding graphics and sound to what the user is experiencing." (British Computer Society, 2014). Despite this, there is a variation of Augmented Reality known as Mixed Reality (henceforth abbreviated to MR) which Benard Marr explains as "*Mixed reality technology allows real and virtual elements to interact with one another and the user to interact with virtual elements like they would in the real world.*"(Marr, 2021). Whilst both variants are regarded as aspects of AR technology, an implementation progresses into MR when users granted the ability to actively interact with the virtual content. However, the lack of a standardized metric for delineating the precise conditions under which this transition occurs leaves the definition open to the discretion of individual application creators.

These differ from Virtual Reality (Henceforth abbreviated to VR) which is defined by the Virtual Reality Society as "a three-dimensional, computer generated environment which can be explored and interacted with by a person. That person becomes part of this virtual world or is immersed within this environment and whilst there, is able to manipulate objects or perform a series of actions"(Virtual Reality Society, 2017). This differs from AR or MR on the fundamental foundation of how the virtual content is presented to the viewer; AR and MR seek to overlay virtual content with the real environment of the user but VR seeks to generate an entirely new virtual environment for them to become immersed within, replacing the users world instead of building on top of it.

1.3. The National Holocaust Centre & Museum

The National Holocaust Centre & Museum is a museum in Newark, Nottinghamshire dedicated to preserving stories from the Holocaust. The museum houses several exhibits (The National Holocaust Centre and Museum, n.d.), including the only exhibition in all of Europe designed for primary school aged children. The Museum has utilised technology to enhance the experience at their exhibits before, including a mobile phone application for The Journey titled *Leo's Story* (Beth Shalom LTD, 2020), an AR narrative experience titled The Extended Journey (Jin et al., 2020) and an interactive storytelling experience titled Interact (Ma et al., 2017). These technological experiences can add new complexity exhibits by allowing visitors to engage with the learning material in new and interesting ways, including ways that otherwise would not have been possible. Considering that survivors of the Holocaust are now elderly, preserving their stories using technological mediums have become more important than ever as soon new generations will no longer be able to experience first-hand accountings. As such, being able to utilise technological mediums for educations, such as AR or VR, are essential for allowing these stories to continue being taught by those who personally experienced them, even if the medium can be considered indirect.

1.4. Interaction Methodologies

The Interaction Design Foundation defines Human- Computer Interaction (Henceforth abbreviated to HCI) as "a multidisciplinary field of study focusing on the design of computer technology and, in particular, the interaction between humans (the users) and computers." (Interaction Design Foundation & Dix, n.d.). Interactions with AR systems is necessary for users to engage with the virtual content beyond just witnessing or listening, however this is often quite limited depending on the hardware. VR devices such as the Oculus Rift or the HTC Vive included bespoke controllers for the user that included spatial location, motion tracking and a combination of buttons and analogue sticks to allow for the user to have a full range of potential interaction methods.

AR devices by comparison often do not include controllers or have limited means of virtual interactions. For example, the HoloLens includes a peripheral called the Clicker (Microsoft, 2022d) that simulates a mouse button click, and the device is capable of voice-recognition commands within a limited capacity, but no sophisticated set of controls comparable to those that are native to standard VR peripheral controllers. Similarly, the Magic Leap One includes a controller with some more advanced functionality such as a touch pad, a pointer and four buttons, however this is also simplistic when compared to VR controllers. Logistically, this can be attributed to the intended functions of the hardware; VR devices were primarily created for computer games or VR experiences, both of which require a broad range of inputs as to not limit the potential gameplay functions for an end user, whilst AR devices are more typically built for more generalised usage that do not strictly require complex inputs.

Developing applications for AR devices comes with the stipulation that user inputs must be considered at every stage of creation as any potential features off the app must be considered against how the user will actually get to utilise it.

1.5. Audiences for AR applications

AR applications for educational purposes are traditionally designed for school-aged audiences, with the focus of the application being on how it can supersede traditional classroom learning resources such as textbooks or teacher-lead sessions. This is not the case for all such applications however as there is increasing interest in deploying AR and VR in Museum environments as supplemental learning tools that can add novelty to exhibits or otherwise serve as an additional medium through which to convey information to visitors. As such, there is the growing potential for AR to be used as a powerful learning resource for adult-aged audiences as well, however existing literature on this topic is limited and does not explore this avenue, leaving a gap in existing knowledge regarding the suitability of such tools for post-school audiences. Prior literature suggests that adult audiences are slower to learn how to use computer-based solutions (Kelley & Charness, 1995) which could prove to be a limiting factor in how effective AR or VR may be when considering that the process of learning to interface with a system on a basic level may be detrimental to a learning experience, however this remains unsubstantiated through existing literature.

1.6. Research Questions

Despite the influx of technological availability, the public consensus on AR is that it is always beneficial to end-users regardless of the context. Whilst it is true that the technology can be used to provide additional information or alternative interaction methods, are these additions necessarily as beneficial to users as nontechnical methods? Specifically for education, does the use of AR result in users retaining additional information when compared to traditional learning experiences? When deploying an AR Learning Experience, does the physical location of the user impact how much of that information is retained? Does the technology used to facilitate AR have any bearing on information retention? And what of the age of the user, do different age groups respond differently to how much they can learn from an AR experience? To answer these points, the following research questions will be asked:

1. Does AR improve information retention rates when compared to a traditional classroom learning experience?
2. Does the technology used to implemented AR impact how much information is retained?
3. Does the physical location of a learner impact how much information is retained from an AR learning experience?

4. Does the age of the learner impact how much information is retained from either method?

1.7. Aims and Objectives

This study seeks to discover the efficacy of AR for delivering educational content to adult audiences and identify if the participants age, delivery medium or physical location play significant roles upon the amount of information retained over a long-term period. This could potentially lead to better quality technology-based learning experiences for adult audiences that can fully utilise the benefits of AR mediums or locations.

Research Objective 1: Produce a set of AR applications for the National Holocaust Centre & Museum to provide new means of visitor engagement with the learning content and to preserve the testimonies of the survivors of the Kindertransport.

Research Objective 2: Test identical educational content through two different implementations of AR and identify if the method of deploying AR impacts the amount of information learned and retained over a delayed period. Compare this against a control group with no access to technology.

Research Objective 3: Test the AR applications at different locations, the University and the Museum, to identify if the location of deploying AR impacts the amount of information learned and retained over a delayed period.

Research Objective 4: Identify if the age of participants played any role upon the amount of information they were able to learn or retain over a delayed period.

2. Review of Literature

The field of AR has been utilised across educational facilities and institutions in varying capacities since its inception, with new technological advances or software solutions providing and enabling new methods of implementing it (Challenor & Ma, 2019). However, the use of AR for educational purposes does not exist in isolation, particularly in the context of a project also seeking to use games technology for digital heritage and communication of history. As such, this review of literature does not exclusively seek to examine how AR has been used in education, but also the broader fields that inform the design of such an experience, which includes fields such as games studies, games development, museum and heritage studies, educational research, and work concerning accuracy, authenticity, memory and ethical design. These fields contribute different and varied perspectives on the development of the proposed project; games studies and game development to help establish how interaction, engagement and design choices shape experience. Museum and heritage studies provide context on how prior study has interpreted and communicated historical materials. Educational research frames how learning outcomes may be supported. Lastly, ethics scholarship helps to contextualise the challenges of representing these difficult areas of history in a responsible and sensitive manner, as not to cause undue harm or distress those impacted by it. To this end, the studies discussed in this review have been categorised according to which fields they most closely align with and how they have been considered for informing the study.

2.1. Games Studies and History

Although the use of AR technology is the primary focus of this study, it is essential to first explore how Games Studies have been used for the depiction of and education of history, as although the mediums may vary, these studies remain foundational in how games technology is used for teaching purposes. In *Digital Games as History*, Chapman (2016) argues that games are important for teaching history due to three main reasons; their popularity among players, that flaws within games as educating tools for history are shared with other forms of media, and that games as history are "understudied". Within the book, Chapman outlines two models for presenting history in games: realist simulation and conceptual simulation. Realist simulation is the practice of trying to accurately depict history within a game in all contexts, including narrative and visual direction, with games such as *Assassin's Creed 2* and *Mafia* being used as examples due to their attempts to depict the eras and cultures in which they are set with a high degree of fidelity. Conceptual simulations, by contrast, are games that engage with the past without attempting to reproduce it accurately or literally, with games such as *Sid Meier's Civilization V* being used as an example, in which players control a historical civilization but have the freedom to develop it however they wish in terms of cultural and technological development, diplomacy, militaristic policies, and so on. From a game development perspective, the argument between these methods is generally discussed in terms of mechanical complexity; realist simulation games generally tend to focus development time on visual fidelity and realistic depictions of historical concepts, whereas conceptual simulation games instead tend to focus on complex gameplay mechanics and procedural rhetoric that may not always be fully visualised on screen. With regard to creating a history game-based learning experience, the choice that must be made between simulation methods will ultimately depend on which aspect is more important: depiction of realism, or emphasis on gameplay complexity.

Depiction of history in games has been a point of contention, particularly with regard to games being a younger medium than other established media such as film or television. McCall (2020), in his writing on games as a historical medium, opposes the viewpoint that games should be decried for inaccuracies, instead arguing that games and board games are historical learning resources and that they do not need to be "colonized by academic historians". To challenge these prejudices against games, McCall presents the Historical Problem Space Framework as a way of analysing and understanding historical games so that they can be considered and designed as games whilst still supporting historical educational practices. The four components of this framework are:

1. The player character representing a historical actor, though not necessarily a notable historical figure, who is tasked with designer-made goals.
2. A game world that simulates history, such as historical locations, historically appropriate gameplay components and other such historical trappings.
3. Elements within the game world that constrain the player, such as obstacles, tools, agents, minions, and resources, that the player must utilise, overcome, or work within whilst also adhering to gameplay genre conventions in pursuit of their goal.
4. The player must form strategies, make choices, adopt behaviours and build their gameplay methods around reaching their goals by working with the constraints applied by the virtual game space.

When applied, this framework can help players remain grounded in the historical experience in which they are playing, which is useful in the context of game-based learning experiences because it reinforces that historical understanding is shaped not only by what content is presented, but by how players are positioned within a designed space and what kinds of actions that space allows them to perform. However, this framework is also structured around conventional recreational games with *Age of Empires II: Definitive Edition* and *Kingdom Come: Deliverance* cited as examples, which may not necessarily translate to a serious game or dedicated learning experience as they may not include fully rendered environments or play-based gameplay loops. In these circumstances, the framework should be followed as appropriate to fit the design of the project.

This is not the only writing McCall has published on the use of historical games as learning resources and has continued to advocate on their behalf in subsequent work, such as his book *Gaming the Past* (2023) in which he argues that video games are part of both our culture, and how we shape our ideas of the past. The purpose of this book is to advise educators on how to integrate games into their curriculum, how to approach them as learning resources, and provides strategies for how to use games to teach critical thinking and historical analysis, with a list of games provided that may be of educational value to educators. Whilst this may, once again, not necessarily translate to a game-based learning experience or serious game, it does highlight the importance of game design when creating historical games as they have lasting value as an educational resource long after the primary sales window of a game has ended. For example, one of the games listed in the book as an educational resource is *Emperor: Rise of the Middle Kingdom,* a 2002 city-building game created by the now defunct studio Impressions Games, which demonstrates that the educational value of a game may have lasting value in the same older films and television shows can.

McCall's advocacy about games being part of culture and how games shape ideas of the past is not an isolated argument, with other scholars taking similar positions regarding how players engage with history in the form of games. For example, in their book on digital games and the simulation of history, Kapell & Elliott (2013) challenge the tendency to treat the academic field of history as the only valid framework for exploring history in games, instead considering the idea of "the past" as a more inclusive way of approaching historical content in games. They also discuss the concept of historiography and what constitutes as history, citing that the concept is inherently flawed owing to how fact-based approaches to teaching history require facts to be selected as part of the pedagogical approach, meaning that facts can be omitted or even distorted by attempting to fit narratives. The discussion held here is valuable, particularly with reference to how attempting to adhere rigidly to facts may reduce the capacity for visual and narrative design, however it is also important to note that this discussion is primarily in response to how scholars of history have typically approached games as teaching resources. Consequently, whilst this may be important discourse for designing a historical themed game, for the purposes of a serious game or a game-based learning experience, adherence to a facts-based approach may be necessary if the primary outcome is education rather than entertainment.

Historical accuracy is a point of contention in discourse surrounding history themed games, particularly due to how essential each audience considers accuracy to be in relation to their own circumstances. This was explored by Copplestone (2017) in her study on perceptions of historical accuracy for cultural-heritage in games, in which she sought to interview varying groups of gamers (casual and competitive), practitioners of cultural heritage (traditional and digital), and game developers (indie and AAA) to identify each group's opinion on accuracy. With a sample size of 52 participants per group, participants were asked two questions:

1. What is accuracy in cultural-heritage videogames?
2. Is accuracy important in (your) game(s) which feature cultural heritage? Why?

Responses found that many players and developers associated accuracy with the visual and representational qualities of games in terms of the artistic assets within games, often drawing on materials from their schooling or prior experiences of learning history, whilst many of the cultural-heritage practitioners initially gave different answers before later circling back to similar concerns. With regard to whether accuracy was important, the gamers largely took a neutral stance on accuracy with 94% responding "it depends", whilst developers were more likely to argue that accuracy was either "never important" (54%) or "it depends" (42%). Cultural-heritage practitioners, by contrast, leaned more toward accuracy being "always important" (62%), demonstrating a clear shift in perception between groups. Copplestone attributes this to games having a different set of affordances from other forms of media whilst still being judged by the standards derived from them, indicating that games need to be considered separately from films or television. However, regarding the development of a serious game or game-based learning experience, it is important to identify the stakeholders who will be learning from said game, as player perceptions of a recreational video game designed primarily for player enjoyment will vary from an experience specifically designed to be educational rather than play. Consequently, accuracy is still a requirement if the purpose of the experience is to facilitate learning based on facts rather than adjust history for gameplay purposes.

Accuracy is only a single aspect of this however, as consideration also needs to be made for authenticity. Burgess & Jones (2022) explored this in their study on how players understand historical accuracy compared to historical authenticity in games, which the authors define as follows:

1. Historical Accuracy: factually accurate in the context of examining historical media and fiction.
2. Historical Authenticity: blending historical representation with audience expectations to produce a historical experience that feels factual and generates immersive gameplay.

The authors state that terminology for the two is often used interchangeably by the media, however they are still distinct terms with their own meanings that may not necessarily be understood by players of games, and so their research sought to identify if players understood the terminology. This was done in two stages, first with a dataset of comments being downloaded from online forums for the *Assassin's Creed* franchise, and secondly by posting a qualitative survey to the *Assassin's Creed* subreddit (a community discussion page hosted on the website *Reddit*) using the findings of the first stage to develop questions for said survey. The study found that the respondents' perceptions of accuracy were based on facts, with games being accurate if the games contained a truthful portrayal of history, and that the burden for this was on developers to ensure they had the required knowledge to represent history properly. A majority of respondents identified historical authenticity as including embellishment, citing that authenticity needs to focus more on the look and feel of an era rather than striving for absolute accuracy. However, participants also responded that whilst some liberties can be taken, historical information should be portrayed as close to accuracy as possible. A minority of respondents believed that there was no difference between historical accuracy and historical authenticity, or in some cases believed authenticity required a full alignment with accuracy. Overall, player responses indicated that they are accepting of deviations from historical accuracy, provided the game kept a strong grounding in historical fact. Once again, this research is aimed at recreational video games in which suspension of disbelief is an implied behaviour from players and thus may allow for deviations from reality, however in the context of a serious game or game-based learning experience, taking creative liberties may be highly contextual depending on the topic and the desired learning outcomes.

2.1.1 Games Design & Development

Game design literature frequently frames development as an iterative process in which mechanics, player experience, and communication of meaning are refined through prototyping and playtesting. This is relevant for both recreational games and game-based learning experiences, as regardless of whether the user is a player or a learner, the experience must be created for them to enjoy or otherwise engage with in a meaningful capacity beyond simply clicking buttons because the design requires it to proceed. In their book on Game Design, Fullerton et al. (2004) argue that the designer must be "an advocate for the player" and that the role of the designer is to concentrate on the player experience and making exciting gameplay without getting distracted by other aspects of games development such as art direction or cinematics, which are still important to the process but belong to other specialist roles. This approach emphasises the concept of a "playcentric design process", which encourages designing with the player experience as the core focus of all design decisions and repeatedly prototyping/iteration on that design to ensure the game is engaging. This is particularly relevant to projects that seek to communicate ideas through play, where meaningful engagement depends not only on content but on how that content is encountered through mechanics and interaction.

Meaningful engagement, as previously discussed, is a necessary aspect of design to ensure that games are intuitive, fun and give the player motivation to continue playing. However, as a concept it requires further definition if design choices are to be properly substantiated. In their book on Game Design Fundamentals, Tekinbaş & Zimmerman (2003) frame that there are two methods by which to define meaningful play, which they classify as Descriptive and Evaluative. Descriptive meaningful play describes the relationship between actions taken by the player and how the system responds to that action in a manner that the player can understand. Evaluative meaningful play is when the relationship between the player action and the outcome fit into the rest of the game rather than being isolated, with the player being able to discern the outcome and it being integrated into the rest of the system. Within the context of designing a game or game-based learning experience, it is essential to evaluate designed interactions around these principles to establish whether the interaction is arbitrary, such making the player perform a task simply to break up a long cutscene, or whether it carries meaning for the player and helps them to remain engaged.

Adding gameplay elements to a game-based learning experience may also be a valuable way to foster engagement with learning content, especially for historical topics that may feel distant or disconnected to learners. In his book on the concept of play, Sicart (2014) discusses play as something broader than simple entertainment and instead frames it as a meaningful way by which people engage with and make sense of the world around them. Whilst the book is more philosophical rather than practical in its discussion about the concept of playing, Sicart's broader account of play as a mode of engagement is important context for creating gameplay themed around historical topics; it provides a lens by which learners may actively encounter and engage with concepts that may be difficult to otherwise consider or empathise with, such as time periods, lived experiences or lifestyles that may feel alien to younger audiences. This is important for game-based learning experiences as it suggests that adding gameplay elements is not frivolous or arbitrary but instead helps to foster engagement and allow learners to explore the content in a way that may otherwise feel inaccessible.

Furthermore, whilst Sicart (2014) broadly discusses the concept of play, it is also important to establish why games technology may be suitable for enabling learning experiences that traditional play exercises may not. Whilst digital methodologies can offer a range of benefits, games technology is also a distinct medium with its own formal structures, conventions and appeal to audiences. Foundational game studies work such as *The Medium of the Videogame* (Wolf, 2002) argues that games (and by extension, games technology) should be understood as a medium in their own right. Although much of Wolf's discussion focuses on the definitions of what constitutes as a game and how games use visualisations, data, space and time, it us also useful for considering how players experience games differently from other forms of media. Using the film *Groundhog Day* as an example, Wolf discusses how games allow players to revisit and repeat parts of a game (design of the game allowing) without needing to restart the entire experience, which differs from other pieces of media, such as cinema, that are usually designed to be accessible only in linear order. For the purposes of game-based learning experiences, this is a very valuable benefit as players can repeat sections of the game experience if they need to cover the content again, reinforce understanding, or simply enjoyed something and wished to experience it again.

2.2. Augmented Reality in Education

The concept of using technologies such as AR to enhance educational experiences has been explored many times, each implementing it in different ways and for different purposes, however there are potential benefits to using AR over other forms of technology. For example, in a study by Billinghurst and Duenser (2012a), AR was deployed to a classroom environment for a grade school to augment both a reading comprehension exercise and a physics lesson. The reading comprehension exercise involved using a story book, however results from this test were not published. The physics lesson involved using two groups: a control and a focus group. Each was given a lesson on the field of physics, however the focus group had their lesson enhanced with AR to visualise the theoretical concepts discussed, such as a visualisation of magnetic fields of the earth and magnetic polarity. Both groups were tested immediately after, with the focus group averaging a score of 72% compared to the control group averaging 60%. In a follow-up test four weeks later, the focus group retained an average of 55% compared to the control group average of 45%, indicating that use of AR assists with retaining information. The authors also commented that they found interactivity was an important factor for learning.

Further studies on AR have highlighted Memory Retention as a potential benefit to the technology. Research by Cook (2019) investigated the value of AR when deployed in a Music Technology classroom to identify if students could use the technology to form visual relationships between various components and recognise their functions for practical usage. This study made use of the HP Reveal app for smart devices to augment a paper booklet with a set of instructions upon it. Upon scanning a page of the book, the app would begin to play an instructional video regarding the equipment displayed upon that page, with the AR app keeping the video positioned over the correct location within the book as to not disrupt the participants ability to read the accompanying information on the page. Cook proceeded to observe participants in using the system and relied upon observation as the primary method of data collection used, only using questionnaires to record student feedback regarding their perceived usefulness of the application. As this study did not utilise a control group, nor did it collect or record any quantifiable data, the results may not be reliable as there are variables within the study that are not accounted for. For example, one of the recorded observations was that students who had previously been unable to set up the music system in under an hour had since been able to complete it within 40-50 minutes which is attributed to the AR application, however this suggests that participants had prior knowledge and experience with the system that could influence their ability to set it up, their newfound speed could also be attributed to past experience of setting up the system before. Whilst it is possible that the use of AR may have contributed toward participant performance, this study does not provide definitive data to contribute to the theory.

This is not to say that all studies on the subject have been fruitless however, as other studies have examined the possibility of AR being used to further memory retention in participants. Such was the case in a study by Menon et al (2022) that examined how the technology could be used to enhance nursing education. This study used QR code based fiduciary markers to align its AR content, which took the form of visualised human anatomy overlayed against a training mannequin. Participants used a Magic Leap One AR headset, and the study mentions a controller, but does not describe what controller was used, or what interactions the participants could perform by using it. This study used both a control and a focus group to assess the impact of AR, and both groups were tested on their ability to perform a physical examination, and later were tested again an interval of "two to four weeks" however the authors did not provide a precise timeframe for the secondary testing of each group. The authors also did not disclose how many participants were in each group. Participants from the focus group scored marginally better, however the authors stated that all participants were already performing at a high level prior to the experiment which suggests that whilst the AR may have been beneficial, it only served to provide additional context to information the participants already knew. As such, this study may not be a reliable indicator of the effect of the technology upon memory retention as prior knowledge could potentially have skewed the results.

Other studies on memory retention have used AR as the delivery method for education content, particularly because of the challenges involved with creating AR learning experiences which would necessitate a positive return on the labour investment. Sommerauer & Müller (2014) examined this in their research into the quantitative investigation of the efficacy of AR for learning outcomes, particularly in regard to memory retention. The purpose of this study was to investigate a simple hypothesis: Do Museum visitors learn more from AR exhibits than non-AR exhibits? To this end, the authors created an AR application to augment a mathematics exhibit at the Anonymous national museum, Washington, in collaboration with two other studies. The 101 participants in this study were divided into two focus groups and were provided with an iPad (fourth generation) equipped with the Aurasma AR app that was configured to provide additional information to twelve exhibits in the form of either videos, visualisations and animations. All participants were administered with a pre-test to determine a baseline for their understanding of mathematical concepts prior to the experiment, and were then deployed to the Museum to use the AR app and further develop their understanding. Both groups had access to AR, however of the twelve exhibits, each group only had access to the AR content for six of them and had to rely on the information presented at each exhibit to learn about the others. Post-tests found that the participants had a higher rate of learning for the exhibits that had been augmented than the ones that had not, whilst simultaneously experiencing much higher scores on questions relating to these exhibits when compared to the pre-test scores. This study shows that the immediate impact of AR is beneficial to learning outcomes, however additional data on how much of that information is retained would be needed to fully inform future studies.

Visualisation is useful for fields other than just physics, with other subjects such as history also utilising the technology to demonstrate lesson content. A study by Lim & Lim (2020) sought to implement AR within a Higher Education environment, with a focus on teaching history appropriate for secondary level regarding the history of Singapore. However, unlike other studies, this one did not utilise the technology for visualising historical components or concepts, but instead used it to let participants take notes by sketching in an augmented environment. Participants were given a passage regarding the history of Malaya and were instructed to sketch a "Memory Palace" in augmented space of all the information they thought would be key information. Unfortunately, this test only consisted of five participants and published a very limited set of results, with data from one participant skewed as they had prior knowledge of the subject. There was no control used to establish differentiation between AR method and alternative method, nor consideration for other potential applications of the technology to augment the subject matter. The authors conclude by stating that the experiment served more as a proof of concept, showing that interest exists for using AR for education, however the data does not reasonably inform future development or pedagogical methodology.

Within classrooms, there are opportunities for AR to visualise and contextualise the content of a lesson, however lessons typically have to be planned around the use of technology. A study by Yoon & Kang (2021) instead pursued the next level of education regarding how the technology could be used to augment a Higher Education lecture. In this study, the authors developed an application dubbed the *AR-E-Helper*, an application designed to integrate with a PowerPoint based lecture delivery by augmenting it with three abilities. The first was to access the slides before and after the one that the lecture was currently focused on, the second was to augment the lecture content to visualise the content of the slides, and the third would allow users to take notes on the augmented content. The study discussed several tests on usability and user opinion, however the authors only published data from their final experiment, in which they tested three groups with varying forms of technology; a group with the *AR-E-Helper* application, a group with access to a smartphone to read the lecture slides and take notes on them, and finally a group with no technology but with printed out slides to take notes on. Each group consisted of twenty and each were given an identical lecture on imaginary logic gates. The study found that the AR group responded much more positively to their perception of the learning method and provided higher scores on the post-test Likert chart compared to the other two groups, with participants responding with proclamations that they found the lecture much easier to understand as they were able to re-visit slides or experiment with the augmented content at their own pace, thus supplementing the lecture content in a meaningful manner. Participants also noted that holding up the phone to face the lecture was tiresome and that the size of the screen made note-taking difficult, therefore showing that there are still limitations to the technology. Regardless, this study shows that learners can respond well to AR solutions within a learning environment providing it enhances the lesson content in a meaningful way.

Higher Education has been the topic of several studies when it comes to implementation of AR to enhance learning, particularly due to the structure of lectures. Zhang et al (2022) discussed this in their study on using AR for lectures with a focus on lectures that utilised textbooks during delivery, claiming that if a lecturer utilises PowerPoint for delivery then students will become less focused on the supplementary material. The authors sought to use AR to allow users to scan their textbooks and overlay augmented content, however the study does not provide details on the functions of the application beyond visualising some of the content, nor if it has any interactive components for the users to engage with. This study used a control and a focus group, with only the focus group having access to the AR technology. Both were given a class with the same content (The authors called it "History close to everyday life" but did not provide context on what this history was regarding) and were tested afterward, with a secondary test two weeks later. The scores from the tests showed that the focus group performed better on both tests, however the rate of retention was slightly lower for too. Interviews with participants afterward identified that participants from the control group had to deviate their attention between reading the textbook and listening to the educator, which would often cause them to miss parts of the lecture, as where the focus group was able to utilise the AR content whilst still listening to the teacher. However, one of the advantages listed by the authors could also be interpreted as a potential concern; the use of AR in the classroom for the first time was exciting and stirred interest in the participants. In the instance that AR were to become a permanent fixture within classrooms, would the use of it continue to be effective when the novelty had expired? The authors do not discuss it, but it is a possibility.

Implementation of AR within a lecture hall has varied somewhat, with different studies focusing on varying methods of augmenting lecture content. Whilst others have focused on PowerPoint presentations or textbooks, Bal & Bicen (2016) instead attempted to use a method involving fiduciary markers. This method involved dividing participating students from a Guidance and Psychological Counselling degree into a Focus and a Control group, with the former having access to AR and the latter without. The paper is brief and does not fully detail how the AR was used, as a test is described that discusses how mobile devices were used to scan QR codes to learn about computer hardware, and also states that "all lectures were completed this way until the end of the semester" which does not describe the time range, number of classes or the involvement of AR into each lecture. Participants were tested (the timeline between the experiment and data collection is not specified) and data analysis found that the focus group scored higher on their tests than the control group, however the authors also chose to analyse the scores collected from the focus group based on sex and found that male students averaged slightly higher scores than female students. The authors attributed this to a notion that men are more interested in technology than women, but this is unfounded and speculative. Additional study on the role of sex within the field of AR for education may be required to establish foundational understanding. Whilst this study does indicate that AR may be beneficial for education, the paper is too vague and does not provide enough information to inform future studies.

Lectures enhanced with AR in most studies tend to focus on the same aspect of lecturing; teaching theoretical concepts that can be better visualised with augmented technology, however there are also efforts to use the medium to better educate on vocational concepts too. Such was the case in a study by Shanbari et al (2016) in which the authors used AR to teach construction students about vocational concepts that would directly apply to their chosen profession. The authors collaborated with a local contractor to digitise footage of a construction site and use it as the foundation to create an AR video to educate students on construction estimating, masonry and roof assembly. Participants were divided into three groups; a control group that was only permitted to attend lectures, a focus group that was only permitted to utilise the AR video, and a secondary focus group that was permitted to both attend lectures and use the AR video. Participants were later tested on the content of the learning material and found that although there was no significant difference in results, the focus group with access to both forms of educational content scored higher as the content of each pedagogical methodology had fortified understanding from the other by providing additional context. This study is still ongoing, and the results published are only part of the overall outcomes of the research, however it does indicate that AR is beneficial to a learning environment.

Technology within both the classroom and within society is beginning to transition from an innovative new method of facilitating daily life, to an expected standard within many environments. This was acknowledged by Roopa et al (2020) that focused on the children of Generation Alpha and how complex technologies are an intrinsic part of their daily life. The study argues that learning institutions need to be prepared to deploy an effective technology-enhanced learning environment to accommodate these expectations and that AR would be an appropriate implementation for it. Within this study, the authors discuss the design of an AR system built with Vuforia to teach about AC Generators, however the authors have yet to test their build or collect any data from it. The study concluded with discussions of potential advantages offered by AR, such as the ability to provide virtual resources to institutes that would not be able to afford their real-world counterparts.

This was also the topic of consideration in a study by Yang et al (2023) that identified an issue with education in the field of Robotics, that can often limit the potential of students if the school or college is unable to afford the hardware requirements of the subject. The authors sought to counter this issue by developing an AR application that would allow students to construct and program a robot virtually without the need for real-world hardware. The 75 Participants in this study were divided into two categories; one that would program with the AR-Bot application, and the other would program using Scratch. Each group was tasked with completing a set of tasks with their designated method and also having exams after the tasks. The results found that participants from the AR-Bot group developed better algorithm design and algorithm efficiency skills compared to the Scratch group, whilst simultaneously expressing higher enjoyment of the learning experience. The study also found that the deployed method had no effect on academic achievement, which the authors claim to contradict previous research, but the authors attributed this to the means by which academic achievement is measured. Whilst it is undeniable that the use of AR technology allows for learning opportunities that would otherwise be unavailable, this study does also suggest that there are factors aside from the interactive nature of AR that contribute to academic achievement and potentially even memory retention.

A concern of implementing AR within classroom environments is the technical understanding involved to implement, maintain or troubleshoot the system consistently. For AR designers and developers, this notion is intrinsic to the process of building a system and so is of little concern, yet to an educator who is not versed in the creation or usage of such systems, there is a greater possibility for error. These concerns were addressed in a study by Lytridis & Tsinakos (2018) in which the authors used the *ARTutor* (AETMA Research Lab, n.d.) platform to deploy AR content to classrooms in a Higher Education institute. This application uses a combination of a web platform and a smartphone application, with which teachers can upload scans of textbooks to the web server and choose augmented content to display in the form of videos, audio files or 3d meshes and select where to display it in the book. Users can then point their Smartphone cameras at the pages and the server will load the AR content directly onto the page, thus giving educators far more control over the types of content shown and where it is displayed. This also provides an entirely new advantage; learning materials that were not designed for AR content can be retroactively augmented to be expanded on in new ways not foreseen by the original authors. Within the context of this study, the authors arranged for 205 students to participate who were divided into two groups; the first was tasked with implementing AR technology into educational resources using the *ARTutor* application, the other group was tasked with evaluating the usefulness of the AR content. The results found that the novelty of the process provided benefits to learners and that the use of 3d models or videos were the most impactful toward learning. Results also found that there were reliability issues due to bugs within the application, and that students using the application were less likely to communicate amongst each other during the learning process. Although this study does demonstrate some consideration for the logistical issues of deploying AR learning experiences, it also comes with the caveat that it was only tested by students at a University; additional research would need to be performed to determine if the logistical considerations would change if it were teachers and students using the application at other stages of education.

Technological familiarity is not the only concern for using AR within the classroom however, as there are also concerns for the wellbeing of students when such systems are used. A study by Hsin-Kai Wu et al addressed this in their review of AR (2013a), wherein the authors explored the challenges of utilising AR for educational purposes. One of the identified challenges was the concept of cognitive or emotion overload; the scenario in which a learner can be overwhelmed by the technology and the process of learning how to operate it, which can be further exacerbated by being required to perform complex tasks or functions as part of the design of the system. Most headsets, such as the Microsoft HoloLens, will typically prompt the user to take a tutorial upon first launch of the hardware to familiarise them with the basic functions of the device before allowing them to proceed to running third party programs or applications on it, thus ensuring that they will not suffer the effects of overload. However, academic studies rarely give mention to if these tutorials or similar learning content was provided to users before a study commences, leaving the possibility that users may have been overloaded by the experience and the potential for results to be skewed. The authors of this study also identified that gameplay may be a contributing factor toward cognitive overload as learners may fixate on the playable aspects of the learning experience rather than taught content, which is further impacted if the provided gameplay is challenging or includes complicated mechanics that can detract from learning.

2.3. Augmented Reality for Holocaust Education

Holocaust Museums and memorials are sites dedicated to preserving facts and testimonies from the 1930s to the mid-1940s, with an emphasis on educating audiences on not only the Holocaust itself but also the events leading up to it that allowed it to happen. To this end, many Museums seek to enhance their exhibits with videos, audio recordings or any other multimedia that can add faces and voices toward testimonies to assist with humanising the victims, such as *The Journey* exhibit at the National Holocaust Centre & Museum that uses projectors with video footage to both create a narrative structure for younger audiences along with showcasing testimonies from actual Holocaust survivors. This exhibit was augmented by Yunshui (2019) to add an additional learning experience to the same space to add a new educational opportunity for older audiences without the need for expansion of the physical facility. This project expanded upon the narrative structure of the exhibits by adding an AR visualisation of the characters from it, fixating primarily on the fictional character of Leo and the transpiring events that lead his parents to send him to England via the Kindertransport. Using a HoloLens, users can witness a narrative scene that uses the full spatial features of the device to place virtual characters within the physical scene who can walk around, talk with each other and even sit down on furniture in the exhibit, whilst the users observes and has the options to influence the narrative by selecting responses for characters, however the branching pathways inevitably converge back to the decision for Leo to evacuate. Although this project is part of a study, there are not yet any published results from it, however it is indicative of a desire for Holocaust exhibits to be augmented using newer technologies.

This is not the only narrative experience at the National Holocaust Centre & Museum, as other research has also implemented AR based story experiences at their facility. Narrative experiences are an integral part of teaching about the Holocaust due to the sheer scale of it; most educational will fixate on the numbers and the methods but to truly understand the insidious nature of genocide but the stories of individuals are needed to contextualise events and reinforce the humanity of the victims and prevent them from becoming just a statistic. Such was the focus of a project by Ma et al (2015) to build an AR narrative experience that digitised an actual survivor of the Kindertransport as a 3d model, integrated with videos and a huge range of recorded audio responses. Using a language parsing system, users can ask questions to the hologram, and he will respond with an appropriate answer where possible. The purpose of experiences such as these grows increasingly important with the passage of time as the survivors of the Holocaust are now elderly and soon there will be no more first-hand accounts of the event available. Digitised accounts and experiences will be the closest preservation of this part of history still remaining and future generations will rely upon them where possible.

Other Museums are also seeking to enhance their exhibits with AR, both to further expand upon the multimedia content used along with adding interactive elements that allows visitors to engage with exhibit content more actively. An example of this is the U.S. Holocaust Memorial Museum, which augmented one of its exhibits using a smartphone app (Dean, 2018). *The Tower of Faces* exhibit is a room spanning three building floors that contains photographs of the Jewish residents of the town of Eisiskes who were mostly killed by paramilitary forces of Nazi Germany during two days of mass shootings. The photographs in the exhibit display pre-war photographs of life in the town of over a hundred families. This exhibit was augmented with an AR app that, upon having the user's smartphone camera pointed at a photograph, will overlay the photographs with information regarding life in the village, along with details of the individuals displayed in the images along with whether or not they survived the Holocaust. Although this application was not part of an academic study, it does continue to indicate that there is a trend of interest in using AR technology to enhance Holocaust Education.

Preservation is an important aspect of AR learning experiences as the technology does not just allow for enhancements of existing exhibits, but also the reconstruction of ones that may no longer exist. This was the case in a study by Kerti (2017) that was conducted at the Lager Sylt concentration camp, a camp on the island of Alderney that was used as a labour camp between 1942 to 1944. Prior to the island being captured by British forces, the commandant ordered the facilities to be burned, leaving very little left of the concentration camp and rendering most of the events of it lost to history, resulting in very little knowledge of what had transpired there until recently (Weisberger, 2020). Consequently, there is not much of the site left to preserve for historical or educational purposes. However, by utilising AR technology, Kerti was able to create a generalised replica of the approximate location of the camp by using simplistic shapes that were rendered in two hues; white for buildings that were documented to be historically accurate for location and scale, and grey for buildings for which the precise dimensions and locations are unknown or not sufficiently documented. These geometric representations do not contain complex shapes or texture data as there is insufficient information to accurately reconstruct them, which results in a simple but elegant use of the technology to fully inform audiences of both the history of the island, as well as which areas are partially lost to history with no ambiguity to that fact.

The Maitland Holocaust Museum also utilised AR for one of its exhibits by implementing a project by Stapleton and Davies (2011a) within its facilities. This system was designed to enhance the available information at the museum whilst also taking on the emotional challenge of engaging audiences with the bleak and pessimistic content matter, with the authors commenting that the subject matter is often so distressing or depressing that many prefer to ignore it unless the story has an uplifting Hollywood-style ending that provides closure to audiences; however such stories from the Holocaust were few and most ended in tragedy. To this end, the authors instead focused on visualising the content of a journal to display the life of a child through the progression of the Holocaust through three different environments; a family home, a ghetto apartment and a concentration camp bunk, with augmented content of visualisations or audio (contextual based on location) designed to invoke the imagination of participants to consider the context and dangers of each environment. This project was also a proof-of-concept piece, with the authors mostly discussing the design and implementation rather than experiments and data collection, however the authors did convey the ethical considerations of building an AR scene for sensitive subject matter such as the Holocaust.

Immersive Technologies expand to mediums aside from AR however, and alternate forms of implementation have been experimented with such as Virtual Reality. The Illinois Holocaust Museum and Education Centre is a learning facility that has implemented a Virtual Reality (henceforth abbreviated to VR) experience (Ulaby, 2022) to teach the story of George Brent, a survivor of the Auschwitz-Birkenau concentration camp. VR Learning Experiences for the Holocaust are generally an area of concern for ethical reasons (Challenor & Ma, 2023) with the United States Holocaust Memorial Museum advocating against the use of simulation exercises to teach about the subject (United States Holocaust Memorial Museum, n.d.), however this experience does not attempt to simulate any content for the user. Instead, the user is taken through a guided video tour of the concentration camp with Brent superimposed over photographs and charcoal drawings of the site as he discusses his experiences, with the user instead learning about the camp from the perspective of a museum visitor rather than a participant within a simulation. This learning experience was also not tied to an academic study but demonstrates that multiple forms of immersive technology are being utilised to preserve the testimonies and history of the Holocaust whilst receiving positive responses from both curators and audiences.

2.4. Augmented Reality in Museums & Heritage Sites

In many regards, it is simple to focus entirely on the advantages of AR and some of its possible use cases, however caution should be taken when addressing digital visualisations to ensure they are not obstructing or misrepresenting the history and heritage they are intended to preserve. The London Charter (Denard et al., 2009) provides a framework for the responsible use of computer-based visualisation in cultural heritage, including AR, arguing that such methods should only be used where appropriate and that their evidential basis, interpretive choices and uncertainties should be clearly documented. This is done via the six principles of the charter:

1. Implementation: Planning for how the charter's principles will be applied on a per-project basis.
2. Aims and Methods: Only using computer-based visualisations when it is the most appropriate method available for the purpose of the project.
3. Research Sources: all sources used to create computer-based visualisations should be clearly identified, selected and evaluated in a structured way.
4. Documentation: The project should be documented and presented clearly enough for others to understand and evaluate, including the visualisations and the outcomes of the project.
5. Sustainability: Visualisations and their documentation should be developed to support long-term use, including migration to new platforms or emulation support.

6. Access: Visualisations should be created and shared in ways that enhance access to cultural heritage either to support accessibility, or to assist with preservation of things that may be lost, endangered or destroyed.

Via these principles, the charter frames visualisation not as a neutral display tool, but as an interpretive act requiring critical accountability so that users can understand and evaluate them. For the purposes of AR learning environments, developing an application that adheres to these principles is beneficial for both academics and for the general public, as it provides transparency and accountability for both the created visualisation along with the information it conveys.

Learning environments are not limited to just classroom facilities and AR has also been used to augment spaces such as Museums or Heritage sites to further visualise or contextualise the content of their exhibits or facilities. This was the focus of a study by Keil et al (2013) that sought to implement AR at the Acropolis Museum of Athens in Greece. AR was used to add a narrative component to the exhibit by adding a virtual character of a horse who acts as a narrator with two different pre-sets, one version for child audiences and the other for adult audiences to give a more tailored experience depending on visitor age. This application also added visualisation components, such as adding a visual to an architectural ornament of Medusa by making her eyes glow red should the user look at it or adding colour back to a statue. Unfortunately, this paper did not publish any results from testing and only served to discuss the implementation of the method, however it does show that there is interest from both the public and Academics in implementing AR within these learning spaces.

Although museums serve as excellent preservations of history, they often serve as visual and auditory displays only with no means for users to interact with historical content. Kyriakou & Hermon (2019) endeavoured to change this in their study on using AR inside Museum environments and heritage sites. This project involved creating digital versions of artefacts for the Acropolis Museum of Athens and rendering them inside of Unity, using components of Vuforia to handle AR rendering. Participants were able to interact with these digitised artefacts using a Leap Motion sensor that was connected to a laptop, allowing users to interact with virtual objects in a limited designated space. The experiments performed by the authors were intended to focus on the usability of this system to determine how users found the interaction methodology. Results showed that participants enjoyed using the system and were eager to interact with it, along with discovering that users who had experience playing video games were faster to adopt to the control scheme than those who did not. Whilst this demonstrates that users are eager and excited to use technological implementations inside of learning environments, it only offered limited exploration for participants as all their interactions had to be performed in a designated area, limiting the potential to expand this system to entire exhibits.

Whilst visualisation is a useful feature of AR technology, it is not the only potential usage and can be used to enhance experiences in alternative ways. AR also includes the possibility of using spatial sound to augment and environment with audio too, as was the focus of a study by Kaghat et al (2020) in which the authors enhanced exhibits at the Musée des arts et Métiers museum using audio-based AR. The authors built a spatial AR system to compare against the museums official audio guide to provide visitors with a more immersive and personalised experience that would follow their individual interests rather than following a generic guided pathway designed by the museum. This system, dubbed *SARIM*, augmented several displays by playing ambient noises related to specific artefacts, such as the operational sounds of a printer or a typewriter, etc. Upon approaching the display, the system would shift to instead playing an audio description of the artefact with narration, testimony or dialog. Participants also had some control over the system and could perform limited interactions with the use of head movements, such as the ability to halt audio by shaking their heads or control the volume by leaning. Participants in this experiment were part of two groups of nine, with one group using the *SARIM* system and the other using the museums audio guide. Results found that participants using the *SARIM* system spent longer listening to the artefact audio than those with the audio guide, but there was no difference in the number of artefacts visited during the experience. Both groups were also tested for their subjective opinions on the usefulness of their system in terms of reactivity, satisfaction, understanding and ease of learning, with the SARIM group achieving higher scores for each category. From a usability perspective, this study shows that users respond well to AR learning systems and the benefits of the personalised experience they can provide can be superior to that of traditional learning experiences provided by museum environments. With a combination of audio and visual components, there is potential for museum exhibits to be completely revolutionised.

Aside from logistics, there are other factors to consider when considering the implementation of AR within a Museum facility, such as the value generated for the Museum when factored against the cost of commissioning and deploying the technology. Dieck & Jung (2017) examined methods of analysing this dilemma in their study on taking a Stakeholder approach toward AR development for museums. A Stakeholder approach is an analytical method defined by Robert Edward Freeman (2010) for business management that classifies the range of potential stakeholders of a business into two groups; external and internal and attempts to measure how these stakeholders are better served by the business rather than by one of its competitors. Typically, in business these stakeholders will be the business owner, its employees and administrators, its creditors, customers, shareholders, etc. Within the scope of a museum environment, Dieck & Jung re-defined the stakeholders to two new groups: individuals (community representatives, managers, trustees, etc) and groups (schools, visitors and volunteers) and analysed how these stakeholders would be better served by the addition of AR technology into the environment of an undisclosed small museum with approximately 15000 visitors per year. The authors collected a group of participants that were codified based upon their stakeholder role within the museum and interviewed them to identify the perceived value that AR technology could provide to the facility. Participants were given an explanation of AR and were shown a short video demonstrating the use of the technology but did not interact with any AR technology themselves. The value found from the interviews was divided into several categories: Economic, Experiential, Social, Epistemic, Historical/Cultural and Educational, with each category having its own benefits such as increased sales, attracting new markets, creating new content for engagement, personalised learning experiences, stimulating interest in history, and many more. The study concludes by discussing how AR is perceived as having strong value for both internal and external stakeholders, with each group prioritising different benefits but all standing to gain from the use of the technology in varying regards. This shows that audiences both internal and external to museum environments have a high perceived value of AR technology and that responses to it are positive which would prevent any societal objections to deploying AR applications to such environments in future.

Museum environments and heritage sites often take painstaking measures to present their exhibits or locations in ways that are engaging and authentic to history, yet if visitors are exploring these locations using AR tools, there is a risk that they may not be paying attention to the physical learning content itself. This was raised in a study by Haahr (2018) who addressed the complications of location-based AR applications citing *Ingress* and *Pokémon* Go as examples and stating that players of those games can become so immersed in the applications that it leads to accidents occurring. Instead, Haahr discusses a goal for AR applications, called Imaginative Immersion which is defined as "game experience in which one becomes absorbed with the stories and the world, or begins to feel for or identify with a game character", and argues this is more appropriate for cultural heritage games as they align the game world with the users physical environment rather than encouraging them to only concentrate on only one. This was demonstrated via an application called *Bram Stoker's Vampires*, deployed at Trinity College Dublin, in which players explored the college using an app that allowed them to search for paranormal encounters and scan them using their phone's camera to "capture" ghosts, represented as AR characters themed around vampires. Upon successful capture, the application provides a photograph and the narrative details for the captured character. This application makes use of two benefits of AR: location-based events to encourage exploration, and a photograph mode that forces the player to examine and explore their physical environment in order to search for the ghost character. Haahr argues that this helps to blend the game world with the physical one and supports imaginative immersion. This study did not include testing or publication of results, which would have been beneficial for quantifying whether this method is appropriate for helping users engage with their physical environment. However, it still demonstrates that consideration should be given to encouraging the user to augment the environment rather than replace it.

The nature of augmented reality applications must also be carefully considered, particularly with regard to what kind of experience is being created and how learners will engage with it. This was initially discussed in a conference proceeding by Barbara et al. (2021) who raised concerns regarding the ethical design and deployment of interactive digital narratives, and then later explored this topic in greater depth in a subsequent paper (Barbara et al., 2022). In the follow up study, the authors evaluated an AR application designed for The Sacra Infermeria, a historical hospital built by the Knights Hospitaller in the 16th century in the city of Valletta that has since been repurposed into the Mediterranean Conference Centre. An AR application was developed for the conference centre to allow visitors to learn more about the history of the building (Azzopardi, 2020) either by downloading it to their own phone or by using a tablet device provided by the centre. Visitors are taught to use the application by a tour guide and are then permitted to use it to project vignettes showing typical scenes from when the building functioned as a hospital. The AR content is entirely markerless and allows users to position augmented content as they wish, even outside the confines of the exhibition if they so wish. Additionally, the application also includes mini games designed to be played on the roof of the building, in which players either shoot cannons at 16th century Ottoman boats in a simulation of the Great Siege of 1565, or instead shoot machine guns at planes during a simulated World War 2 battle. Barbara et al evaluated this application with a group of eleven participants, each an academic in the field of interactive digital narrative but from different fields and backgrounds. The participants found that the application toned down the atmosphere so noticeably that it misrepresented the heritage site itself, citing, for example, the visualised caregivers being immaculately dressed when they were supposed to be tending to the sick and injured, which was felt to insufficiently convey the pain and suffering expected from a hospital of the era. The participants also raised concerns that the application had been gamified for the purposes of entertainment and display via social media, citing that the games were historically inaccurate as the city of Valetta did not exist during the Ottoman times, and there is no record of anti-aircraft weaponry being installed to the roof of the building during world war two. There was also a concern raised regarding the design of the app for a historical place of suffering, and how the social media-centred design had attempted to turn the location into an attraction for children, which the authors compare to the practice of taking selfies at Auschwitz. Based on their analysis and findings from the participants, the authors identified four improvements for the Sacra Infermeria AR application that they state can be generalised for other AR narrative museum experiences:

1. Provide an experience not possible through other means.
2. Foreground the historical complexities of the site in a way that provokes thought.
3. Understand the opportunities and challenges of AR as Hyper Reality.
4. Deliver production standards that meet user expectations.

For the purposes of a new AR learning experience for a museum, this provides some invaluable insights. Most notably, it suggests that whilst gameplay elements can be added, and may even be enjoyable for some audiences, they do not necessarily contribute to learning and may instead result in visitors leaving with incorrect historical assumptions, for example, believing that the site was used to host anti-aircraft weaponry during World War 2. Furthermore, any attempts to convey history should do so accurately to facts and visualise events as closely as possible to how they were, rather than attempting to sanitise them as this presents an incorrect version of history that, context depending, could be interpreted as disrespectful to those being depicted. This study also aligns with other literature, such as how the designed experience should only be created if the learning content is not possible through alternative means (Denard et al., 2009)and that it should be designed with the users in mind (Fullerton et al., 2008).

Further studies have been undertaken on the benefits of deploying AR within the scope of Heritage Sites, including a study by Boboc et al (2019) The authors of this study argued that although there are benefits of using the technology, study also needs to be performed into user acceptance of such systems as any educational benefits are mitigated should users be hesitant or reluctant to use AR. To test this, the authors created an AR Application to educate on the Roman poet Ovid and tested it at three locations where Ovid was renowned to increase the possibility that potential participants were aware of him. These include Constanta in Romania and Rome & Sulmona in Italy. Each location had a different version of the application to include localised content, such as having a visualisation of a Roman house placed over the ruins of a real house in Constanta, etc. The AR contents of this application included visualisations of 3d objects, buildings and fully animated character models, along with audio. The application was built using Google Tango for motion tracking, area learning and depth perception, and was deployed using Lenovo Phab 2 Pro devices. Participants were divided into groups based on location, but this test only used focus groups and no control group, however each group was given a slightly varied AR experience due to the aforementioned location differences in AR content. Participants were all given a short tutorial in the usage of the application and were then allowed to explore the scene for as long as they desired. Upon completion, all were given a questionnaire to test for the usability of the application along with comprehensibility, manipulability, enjoyment and usefulness. The results found that participants thought the application was easy to use and enjoyed the experience although the usefulness showed some variation in score which the authors attributed to the type of AR content available in each location. The authors conclude that the usability and interaction from their model was appropriate, but did not provide any definitive results to support their method of deployment over others, nor any consideration for if their mobile AR deployment may have benefits or disadvantages compared to head-mounted applications

Although not strictly an advantage of AR learning experiences uniquely, another advantage of AR was raised in a study by Falami Berbarduzzi et al (2021a) in their study at the Pavia University History Museum. In this study, the authors worked with the museum to expand its use of digital technologies to help attract new audiences, including the use of AR. The authors had explored alternative digital technologies to implement including VR and even the creation of a game app, however they ultimately decided on AR to allow the museum to maintain its current appearance, with no alterations required to the furnishings to facilitate the use of the app, along with the added benefit that the learning content could still be made available within the app without the use of markers and provide a continual educational resource in the future. Design of the application included consideration for hardware, but with head-mounted devices being deemed unfavourable to smartphone applications as visitors would already have their own devices and thus remove both the costs to the museum, along with the operation logistics that may prevent more than a few users from interacting with the AR system at any given moment, due to either spatial limitations or the number of devices available. This study did not collect results and mostly served as a documentation of the development of an AR application for a museum, however the authors did raise an interesting point when discussing the use of their application; foreign students spent more time interacting with the application. This was not explicitly stated by the authors, however museum displays are usually depicted in the national language of the country they are housed in, with no (or limited) support for other languages, however smartphone applications vary in this regard as the use of localisation tools can translate the content of an application into other languages, thus removing a potential learning barrier for learners. Furthermore, accessibility is a concern during software development as users may require different fonts, larger font sizes, contrasting ranges of colour, audio narration or other forms of disability support that would not be logistically feasible for a museum exhibit to fully factor in to their displays, but would be simple to include within an AR learning app to be fully inclusive to a wider range of audiences.

Beyond heritage, AR has also been used as an educational medium for local environments and communities too, with the intention of teaching audiences about surroundings. Such was the focus of a study by Dionisio et al (Dionisio et al., 2016) which aimed to teach tourists about ecosystems in the Laurisilva forest through the use of an AR application. The application was used in conjunction with narrative and encouraged tourists to engage with a story featuring a time travelling scientist and a 19th century physician called Laura Silva, in which the users must assist the time traveller in his search for Laura's lost herbarium, which contains knowledge about the forest and its biodiversity. The experience began by showing users a video featuring the time traveller, after which they were then provided with a smartphone loaded with the application and are given two hours to locate Laura Silva's book before the time traveller leaves. This was facilitated by a Samsung smart phone running a Unity-based AR application that uses GPS coordinates to track the user's location and triggering events, such as AR scenes or motion comics, when the user arrives at specific locations. The study states that there are multiple endings, although the criteria for these is not explicitly explained in the paper. The study found that participants enjoyed the story and generally wanted more story-based content, and that the audio-based content was actually preferred over the AR video content because participants preferred being able to look at the physical locations rather than at a screen. Participants also found that the distances between locations sometimes felt too large, and that they would have preferred either shorter distances or more things to find in the surrounding area. This demonstrates that users can enjoy and benefit from AR applications, but that the AR features need to be carefully considered depending on what meaningfully enhances the environment, as anything that interferes with it may reduce enjoyment. It also suggests that when GPS-based AR is being used, users should be given content to interact with at regular intervals in order to prevent frustration.

2.4.1 Accessibility for Learning Experiences

Expanding on this concept further, there are limited studies into the realm of accessibility for AR and how it can be utilised to provide inclusivity for audiences with disabilities or alternative learning requirements. This is a potential benefit to the medium as the use of augmented learning content could possibly provide additional learning opportunities for audiences who may have a higher barrier to learning when taught with more traditional learning materials such as textbooks. An example of this was a study by Herskovitz et al (2020) on the topic of AR and how to make it accessible, something which the authors note has relatively little consideration compared to VR, which has seen lots of studies into how to make it a better accessible medium. In this study, the authors developed AR functionality to enable Blind participants to engage with AR applications, including some backend functionality adjustments to allow 3d objects to be interacted with using the same principles as a standard 2D user interface, along with the ability to freeze an AR scene to permit users to interact with objects without needing to move the device. Following this, the authors then created a series of applications that utilised AR with these features and utilised verbal feedback to give notifications to the users, which upon testing proved to be successful and allowed the users to successfully interact with AR. Within this context, the authors demonstrated that it is possible to design AR to include blind audiences, however additional research would be required to demonstrate the efficacy of the technology compared to alternatives for blind users.

Additionally, Museums have also been the target of research into AR to further explore how the technology can better facilitate engagement from users with disabilities. This was explored by Ahmetovic et al (2021) in a study on making artwork accessible to people with low levels of vision, with a forward point from the authors stating that people with disabilities rarely visible museums, which they attribute to difficulty navigating museums and accessing artworks. The authors also state that museums often rely on audio tours or occasionally tactile feedback mechanisms to ensure compliance with global disability conventions, which is a functional solution for blind visitors, but aren't always appropriate for visitors with Low Vision. To counteract this, the authors developed an AR app called *MusA*, an application designed to work with pre-recorded audio descriptions by scanning paintings and uses them as a visual trigger, a decision that the authors note was made at the Museum Directors request as they believed QR codes would be detrimental to the aesthetics of the exhibits. The application then allows users to select a chapter of the descriptions by pressing the screen, which will then be played, allowing users to listen to, or quickly re-listen to the sections that interest them. On a second iteration of the application, the authors added a virtual mode that would allow users to re-visit artworks within the application without having to physically scan the artwork again. Testing revealed that users were confident using the system and did not face difficulties or inconsistencies with the usage, which demonstrates that developing AR applications for users with vision disabilities provides addition accessibility for Museum exhibits, however this study only pursued user perception toward the system designed, additional data on the efficacy of such systems would be important to further explore the impact of AR versus alternative learning mediums.

Both of these studies focused on users with vision-based disabilities, but beyond this, there is little in terms of published research into the use of AR to benefit learning experiences, Museum or otherwise, in any capacity. These studies also fixated entirely on providing bespoke experiences for users with disabilities rather than exploring how existing experiences could be adjusted to include accessibility options. Although this topic is not the purpose of this study, it is a consideration to be made for AR system design, and a possible future research topic that could benefit users with a wide range of disabilities that might otherwise not be included when designing such learning experiences.

2.5. Games for Museum & Heritage Site Learning Experiences

It is important to explore how other forms of games or gamified processes have been used in the past for educational purposes in Museums, Heritage Sites, or other educational settings for historical events. For example, a very notable example in the field of games for history education is a board game called *The Train* (Romero, 2009), created by games industry veteran Brenda Romero. In the game, the player receives instructions to load people, as represented by yellow game pieces, into a train carriage, which they must get to the opposite end of the board. The game pieces are large and the space in the carriage is limited. Upon reaching the opposite end of the game board, it is revealed to the player that the game is set during the Holocaust, and the train was transporting Jewish prisoners to Auschwitz, or another concentration camp. This game was created as part of an exploration by Romero to identify if it possible for gameplay mechanics alone to capture complex and difficult emotions, rather than relying on visuals, animations, sound effects, or the other typical conventions of games. Only one copy of *The Train* was ever produced, it is not a game that can be purchased or played by the majority of people, but it is a notable game produced for the purposes of how games can be used for history education. However, despite the reputation of The Train, it did not go without critique. Kaufman (2023), writing from a Jewish perspective, critiqued the game for both dehumanising the Jewish prisoners who are represented entirely as blocks with no agency, along with humanising the SS officers the player is positioned to be by making them seem naïve to who they were transporting and for what purpose. This is historically inaccurate as those involved with the operation and logistics of concentration camps were fully aware of what was happening, but Kaufman states "the mechanic of Train tells a different story: that the officer (the player) was loading people onto a Train to Auschwitz without meaning to", thus positioning the player to sympathise with the officer and likens the concept to "identity tourism". Such critiques are important because they demonstrate that emotional impact alone is not sufficient grounds for effective historical representation, particularly when dealing with traumatic or difficult subject matter. This is a recurring sentiment with depictions of the Holocaust in games related media more broadly, particularly where shocking imagery or reveals may be used without necessarily deepening understanding. A similar argument was made regarding the ending of *Call of Duty WWII* (Adam Rosenberg, 2017), in which the player character explores an abandoned concentration camp designed mostly for shock value with no educational benefit. This demonstrates that whilst games can be designed with mechanics to simulate historical actions, full consideration must be made for the historical theme being depicted to ensure that it is considered an appropriate way of representing the subject matter.

This is not the only example of Games being used for holocaust education. Whilst *The Train* used a board game to represent the holocaust in game format, other examples instead use computer games technology for educational purposes. An example of this would be the Anne Frank House VR app (Oculus (Meta), 2018), a Virtual Reality application developed by Force Field VR to recreate the secret annex in Amsterdam where Anne Frank and her family famously hid from the Nazi occupiers between 1942 to 1944. Users of this application can explore a virtual recreation of this annex, either in a free-roam mode, or in "Story Mode", where players are guided by sections of Anne Frank's diary. During their time hiding in the annex, the rooms were furnished, however after the arrest of the family, the nazis ordered the furniture removed, and to this day the annex remains devoid of furniture at the request of Otto Frank, Anne Frank's father. Consequently, the museum of the Anne Frank house museum does not accurately represent the layout of the annex during the occupation, however the VR app includes approximations of the furniture to better simulate the conditions the family lived in. This application does not require users to be physically present in the Anne Frank house museum; it can be downloaded from the internet and used in any VR configuration capable of running the experience, however the museum does offer the application on-site to assist users who are unable to climb the stairs to physically experience the annex. Though not tied to any academic study, this application demonstrates two important concepts; that there is an interest in using games technology to educate on historical areas such as the holocaust, and also that there are cases in which it may be appropriate to make reasonable adjustments to experiences, such as including historical content which may no longer be present in actual museums/heritage sites. However, these should be done on a case-by-case basis with explicit permission, rather than taking liberties with historically sensitive material.

Interestingly, several museums have elected to produce educational content for their own exhibit content in game format but designed it in such a way that users can engage with it without needing to visit the museum itself. This is beneficial for learners who are unable to visit these museums for any reason, along with being useful for educational institutions such as schools that may utilise these resources in their learning content. For example, the Museum of London released an educational experience about the Great Fires of London of 1666 to teach learners about how the fire began along with how it impacted London, however, unlike the Anke Frank VR House App, this application was not built as a bespoke experience for VR, but rather, a set of levels to be played in the computer game Minecraft (Mojang, 2009). As playable levels, learners can download the map files for the levels from the museum website and load them into their Minecraft installation at home, allowing learners to play these levels at their own convenience and engage with the learning content at their own leisure. Again, this project was not tied to an academic study or research paper, but it does demonstrate that museums are actively engaging with gaming technologies to make learning experiences that are engaging and accessible to audiences, allowing for a greater range of learning opportunities and even giving learners some agency in how they access content. For example a bespoke computer game may be educational, but may not necessarily be fun for people to play, however by creating this experience in an established game such as Minecraft, learners will already understand the controls, the game mechanics and the general tools that will be used to create the experience, thus removing the accessibility barriers and allowing learners to be educated on terms they are more familiar with.

Minecraft has been used by other museums for creating educational content too. For example, the Sir John Soane's Museum in London, a museum dedicated to the British architect Sir John Soane, also used Minecraft to create a virtual learning experience (2026). In this experience, learners once again download the necessary files for their installation of the game Minecraft and play them, which puts them into a virtual version of the museum. Inside the virtual museum, there are portals for players to traverse through which teleport them to ancient civilizations such as Greece, Egypt and Rome, in which they explore classical architecture whilst being provided with the means to attempt building their own creations, thus creating a learning experience that teaches the history of architecture whilst simultaneously fostering interest in the subject matter. Additionally, to assist with learning, the museum also offers free classroom resources and lesson plans for educators so they can integrate the learning content from the virtual experience into lesson content, allowing educators to seamlessly transition from using the Minecraft content into traditional lesson content. Once again, this experience does not require learners to travel to the museum, instead allowing for virtualised remote learning with computer game content as the key delivery methodology, along with utilising the technology to allow learners to explore regions beyond the physical boundaries of the museum. Once more, this was not tied to an academic study, but demonstrates additional proof that museums are utilising game technology to expand upon their learning resources and allowing for more immersive ways for users to engage with the learning content.

Minecraft is not the only example of games being used for this purpose, as any game with sandbox or level-creation methodologies could be used for similar purposes. Another game that has been used for museum is *Roblox* (Roblox Corporation, 2006), an online game platform that allows users to create their own games and release them through the platform itself. Roblox was used by The National Gallery in London to create a gamified learning experience for children to learn about the history of art. Titled "*The Keeper Council*" (2023), learners can access this game through the Roblox platform through either a PC or through the Roblox app to explore a fantasy world, solve challenges, meet characters called Keepers and collect paintings with which they can create their own virtual galleries. Developed by StoryFutures China (2023) through the Covid-19 pandemic, the creators stated that initially they did not set out to create a Roblox experience, but they believed it would be fun and impactful for young learners and their families to experience together. Interestingly, StoryFutures is an organisation that claims "to research, prototype and develop immersive storytelling experiences that both enhance visitor experiences on-site as well as allow for the Gallery and the Museum to take experiences to the audience" – however there does not appear to be any research published as part of this project. It is unknown if any publications are planned as a result of this, however it does indicate that research is a possibility of creating such experiences, providing benefits beyond simply creating accessible learning experiences.

In the field of academic literature for museum-based gaming experiences, studies have been conducted to identify the benefits of using games for learning. For example, in a study by Yiannoutsou et al (2009) , two games were deployed on mobile devices to identify the benefits of using them by children at the Museum of Solomos and Eminent Zakynthians, a history museum in Zakynthos, Greece. This included two differently designed games, both made to be played on a Personal Digital Assistant (henceforth abbreviated PDA) and were both designed to be integrated into the museum as seamlessly as possible without needing "extreme" changes to the arrangement of the museum, along with ensuring the design was engaging in such a way that it felt that visitors were "playing with exhibits" rather than simply viewing them. The two games designed for this were titled Donation and Museum Scrabble. In Donation, users play in groups to scan RFID tags in the museum to get more information about the exhibits, which can be stored in the application. The game is also designed to prevent any user from gaining all of the information, meaning that players must collaborate to learn all the information and use it to identify a specific exhibit so that a virtual character can "donate" an artefact to the museum. In Museum Scramble, players compete in groups against each other by being given hints, referred to as "triggers", that have a link to a specific exhibit and can be claimed by scanning the RFID tag at the correct exhibit. If players solve the hint and form the link between the trigger and the exhibit, that specific link becomes unavailable to the other group, thus forming a competition where groups must use the information available to them to create more links than the opponents. The authors report that players of the Donation game developed a task-oriented way of treating exhibit information, which the authors state "helped students to formulate a concrete and clear idea about the exhibits they played with" – this language is somewhat vague but suggests that the game helped to clarify understanding of the exhibit content for the players. Additionally, the Museum Scrabble game is stated to be "similar to those of Donation with respect to user engagement", with the rest of the discussing the challenges of creating clues and triggers for specific exhibits. No full data sets were reported as part of this study and the results discussed are somewhat vague, which may be due to this study being presented at a conference where further clarity could be provided, however the results do indicate that the use of game experiences in museums assists with the learning process and can ensure that visitors have a more comprehensive understanding of exhibit content.

School age children are often the focus for many museum-based games and learning applications. In some cases, the schooling itself is considered a key focus of the outcomes of a learning game, as was the case in a study by Vavoula et al (2009) when developing a mobile phone-based game for school aged children. The study mentions three museums participated in this research, but these were not named, however the D-Day Museum is given an acknowledgement, along with D-Day being a topic mentioned in the study, which suggests the chosen museums were all World War 2 themed. The game produced was called *Myartspace*, a mobile phone-based game designed to provide useful educational information for learners both during a visit and after it, with the developers specifically focusing on making the game a resource for school field trips. Prior to usage, teachers would be given a Teacher Pack and a Lesson Plan for their chosen museum with content to support classes before the trip, during it and for post-visit lessons too, ensuring the content has been sufficiently scaffolded to support educators prior to using the application. During a visit, participants were provided with a Nokia 6680 phone with the *Myartspace* app loaded onto it, which students could use to take photos, record sound and input text, which is then sent to the user's personal repository on the *Myartspace* website. The significance of this is that after the field trip is over, users can log in to the *Myartspace* website and access the media and data they collected during their trip, allowing them to continue using museum learning resources as part of class activities and future study. Qualitative data was published as part of the research instead of statistics or numbers, but did show some interesting outcomes, such as the museums appreciating the application, but arguing that it was not fiscally viable to maintain it due to the cost of the phones needed and the rapid rate of technological advancement in that era. Teachers reported that it was additional work to get the content and website prepared for their lessons, but they felt it was worth it as students had engaged with the content more than they otherwise may have done. Although this study was presented as a game-based learning experience, aside from having a mascot, there doesn't appear to be any conventional gameplay as part of this learning experience, instead working in the same way that cloud-based data collection would on a modern smart device. There is also some irony in the outcomes of this study now, as the data was collected in 2006, a year before the first Smartphone would be deployed to the market, and before culture shifted toward most audiences, including schoolchildren, owning their own smartphones which would subvert the need for an application like this.

Learning based applications are not the sole purpose of games in museums. Other applications have instead sought to use other aspects of a museum, such as its physical space, to create a museum themed game. Such was the case in a study by Rubino et al (2015) in a game built for the Museo Civico d'Arte Antica, an art museum and heritage site in Turin, Italy. As a heritage site with a rich history and a very large interior (which the authors state as having a combined surface of more than 4000 metres spread across four floors), there is significant potential for augmentation via gaming experiences. The authors of this study created a location based mobile game called "*Gossip at palace*", a game in which players interact with virtual characters and engage in a narrative regarding a spy within a royal court. Players get given a backstory, being charged by the Royal Lady Marie Jeanne Baptiste of Savoy-Nemours, to identify this spy. This is done by exploring the museum to search for markers, which loads a panoramic photograph the room and one of the virtual characters from the game rendered on top of it. Players can explore the museum in any order and interact with whichever of the characters they so wish, being presented with interactive conversation trees via the application and a branching narrative depending on conversations held. *Gossip at Palace* also features a randomly generated spy, meaning that the game would have different outcomes every time it was played and two players could end up having different narrative experiences accordingly. The study tested participants from different age groups and found that younger participants found the aim of the game easy, with teenagers and young adults having an easier time than adults and children, who found it more difficult and also found the game interface was not as intuitive. Participants were interviewed for their opinions and findings from the game, with the interviewers asking four factual questions to the users during this interview to identify how much they had learned from the museums content. These questions identified that children learned very little, teenagers learned some information, young adults generally acquired some level of knowledge, and adults gaining the most information from the overall experience, suggesting that adults may be better suited to knowledge retention from such experiences. The authors conclude by discussing that whilst *Gossip at Palace* was an enjoyable experience for participants and showed to assist with learning, it was difficult to design a game to balance both learning and entertainment. The key findings were that the maximum length for a museum-based game is one hour, as any longer can be strenuous for users, and that not being able to finish the game can be frustrating. The authors also reported that aspects of gamification such as experience points and badges/achievements can be good for player motivation, which may be beneficial for the designs of some games. This shows that narrative-based experiences can be engaging for users, particularly when utilising expansive spaces to foster exploration, but that any museum-based game needs to have a tight scope for play time, and ways of keeping players motivated to continue exploring and engaging with the application.

Locations and narratives are recurring themes in digital heritage research, often focusing on encouraging users to explore and giving them a reason to visit each part of a museum or site in search of digital content. This was the case in a study by Nisi et al (2004) who sought to create an AR-based narrative inside a building (the building is not named in the study, but the discussion suggests it was a brewery and holds some form of historical significance.). In this application, the users engaged in a narrative experience called Hopstory, focused around characters from the early 20th century. This was done by giving participants iButtons, a small device that was paired with similar buttons located inside cat sculptures around the building. When a participant pressed their iButton to the sculpture, it would collect the story files from it, that could later be accessed in a dedicated "playback" area to view the story via a projector. The study did not publish formal evaluative results, but the authors observed that participants responded well to the technology, that very few experienced technical difficulties or trouble understanding it, that many users needed refresher guidance when using the playback area, and that most participants made a dedicated effort to find all of the story content before visiting the playback area rather than periodically returning to it between locations. The authors concluded that their method was non-invasive and easy to adjust or remove as required by the location, making it a very simple implementation method without significant installation required. This implementation method is interesting and demonstrates that users are willing to engage with technology-based tools in learning environments, however the method used here may not translate to AR methods due to the need to keep moving between locations. In relation to AR research, this study substantiates how movement through the site itself can become part of the narrative structure (Rubino et al., 2015).

2.6. Pedagogical Methodology for Augmented Reality

Despite rigorous interest from institutions to implement immersive technologies within their educational models, there is still the question of the implication of the technology upon pedagogical methodology and how its usage is either substantiated by existing research, or how its usage can expand upon it. Within this context, it is possible that Augmented Reality may not fit within the established scope of pedagogy or existing curriculum models and so this section will seek to explore how the use of the technology for educational purposes can align with or even surpass existing theory.

Whilst academic studies have explored the aforementioned concerns, there is another which has not been tied to any individual paper; the risk of seizures from users with photosensitive epilepsy and alternative complications for users with medical conditions. For example, Microsoft list the HoloLens as being potentially dangerous (Microsoft, n.d.) to users suffering from photosensitive epilepsy due to the flashing lights on the visor, as well as a risk to users with pacemakers or other medical equipment on account of the magnetic field and radio frequencies from its components and wireless radios. Similarly, Apple list related potential complications from use of the Apple Vision Pro (Apple, n.d.) along with a warning to consult with a medical professional before using the device. Despite the aforementioned studies and potential advantages to the use of the technology, it may not be suitable for deployment as a replacement to traditional pedagogies as individual students may be unable to utilise the technology due to medical conditions or concerns regarding the possible side effects of devices.

Alternatively, whilst there are potential exclusions for learners based on medical conditions, there are also potential avenues for AR technology to bolster inclusivity within the classroom by adjusting the classroom environment to better support the needs of some learners. This argument stems from an opinion piece rather than a peer reviewed study and additional research is required to substantiate the claims made, however business consultant Joanna Herczyńska raised a point that Neurodivergent children, specifically children with Attention Deficit Hyperactivity Disorder (furthermore abbreviated to ADHD) and Autism Spectrum Disorder (furthermore abbreviated to ASD) are often unintentionally excluded from traditional learning due to the visual and auditory elements of a classroom environment, however both AR and VR technology have the possibility of bypassing these forms of stimulus (2023). The technology could theoretically be used to alter the colour palettes of a room or remove distracting elements that could prevent children with these conditions from engaging with their learning. Whilst this is a fascinating discussion, research would be required to substantiate these points and provide research data to better inform the creation of applications for this purpose, however the point remains that there are potential alternative benefits to AR for educational purposes that have not yet been explored.

2.6.1 Effects of Age on Learning Methodologies

Adult audiences are typically considered to be slower learners than children in many regards, with the general public perception that people become generally worse at learning as they grow older. Havard Medical School (2022) state that this is the result of diminishing attention spans, which they attribute toward the ever-changing neurochemistry of the human brain, resulting in the slower processing of new information along with poorer encoding of information, which the page states is typically noticed by individuals over the ages of 50. This data from the Harvard Medical School is presented in a factual manner without citing of sources, designed to be a concise summary digestible by the layperson without prior understanding of medical science or neurobiology/neurochemistry and as such is a more limited description, however it does serve as an appropriate abstract of the topic for the purposes of informing this study.

Literature has often sought to further explore the concept of age upon academic performance and has found mixed results with it. For example, a study on knowledge retention for different ages was performed by Clark et al (2015), specifically regarding how a group of young adult learners compared to a group of elderly learners. This study created two groups, each with an equal sample size of 20, and created a computer application that would present pictures of faces of human adults to participants. Each face was linked to a specific key on a keyboard, which the learners would have to press when that face appeared on screen. Participants were each given a tutorial to learn this (referred to as the "mapping period" in the study) that last approximately seven minutes before the main testing began, in which the participants were tested for response times and accuracy of their key presses. The purpose of this study had been to gain more data on age-related cognitive decline and yet despite the initial hypothesis, the older participant group demonstrated similar rates of learning to the younger participants, although with slower responses rates and lower accuracy. The authors conclude that whilst age may play a role in the fluency of motor responses, it does not detriment learning rates. This suggests that older audiences may be slower to utilise an AR learning application but learn at the similar rates to younger audiences, making the technology appropriate for all age ranges as a learning resource.

Academic performance is not the only subject of knowledge retention on aging however, as other studies have sought to explore other aspects of information retention. For example, a study by Head & Isom (2010) sought to explore the effects of age on navigational abilities in a digital environment, which the authors split into two categories: Wayfinding and Route-Learning. The authors of this study collected two participant groups: one for each of those aforementioned categories, each containing a subgroup for younger and older participants. Participants were provided with a digitally constructed maze that they had to navigate using a joystick, with landmarks placed around the maze for participants to identify. Participants in the wayfinding group were given fifteen minutes to explore the maze, and then were tasked with locating twelve of the landmarks, along with being provided with a top-down view of the map and asked to mark the locations of them. The route-learning group was given a pre-determined route to follow and were guided by arrows, which they were then tested on without the use of arrows and relying on landmarks to traverse the maze, and were also given the same tasks of describing landmarks and locating them on a map. The study found that the older participants performed worse at wayfinding, taking longer to find the landmarks and locate them on the 2-d map, however the older participants for the route-learning group performed at a similar level to the younger participants. The results from this study suggest that knowledge retention may vary depending on the context of what is being learned. While the authors speculate on the role of the pre-frontal cortex in these differences, they do not provide a definitive conclusion. Without additional input from neuroscientists, it is difficult to determine which types of knowledge are better retained by older individuals. Nonetheless, this study suggests that age may impact knowledge retention differently depending on the specific subject matter, rather than universally affecting all types of learning.

The pre-frontal cortex is potentially a significant aspect of learning as this part of the brain is responsible for several functions including emotional responses, controlling the attention span, decision making, social responses (Fuster, 2015) and also for a process known as encoding (D'Ardenne et al., 2012), the method by which the brain either processes or stores information. In recent decades, the ability to track the development of the human brain has become more readily accessible since the deployment of MRI machines to hospitals and labs, further enabling scientific research on the topic. It has been observed that the brain does slowly atrophy with age (Murman, 2015), with most white-matter atrophy being found in the frontal lobe, most of which contains the pre-frontal cortex. The exact nature of this atrophy and its impacts are still a subject of academic research far beyond the scope of this project; however it is important to establish that there are biological/neurochemical factors to consider when considering the effect of age on knowledge retention and that a cognitive decline over time is expected in most cases. Research has also observed that this can be mitigated with exercise (Bugg & Head, 2011) which adds the suggestion that knowledge retention rates may be higher in adults with higher levels of physical activity than those with lower levels. For the purposes of this study, it is reasonable to assume that the medical science tracking cognitive decline over age will be a general factor over any results obtained.

2.7. Technology-Enhanced Learning for Holocaust Education

Although AR is primarily the focus of this study, there have been alternative attempts to utilise technology to teach about the Holocaust using the advantages that different mediums have to offer. Developing for the same purpose mandates discussion of these projects to either avoid repeating their outcomes, or to allow for detailed analysis of how AR could change the outcomes for the learners or fundamentally change aspects of the learning experiences. For example, in 2008, the United States Holocaust Memorial Museum created a virtual museum exhibit in *Second Life*, an online social simulator/ metaverse, designed to teach audiences about the Holocaust. Titled "*Witnessing History: Kristillnacht, the 1938 Pogroms*" (2008), the exhibit is an environment structured to resemble the immediate aftermath of Kristillnacht and depicts a period specific urban highstreet with broken windows, destroyed furniture, graffiti and propaganda pieces spread around. Visitors are provided with instructions and context as they move through the exhibit through the use of system messages and are provided with a narrative frame that they are fulfilling the role of a journalist, there to observe and document their findings. Functionally, this experience is very similar to a standard museum exhibit and allows learners to explore and learn with information provided for them, the only real difference being how the user interacts with the world, using a virtual avatar rather than being present in-person. This exhibit was not tied to any academic studies and has no research outputs; however it does serve as a good example of how educators are utilising varying technological mediums to teach audiences about the Holocaust.

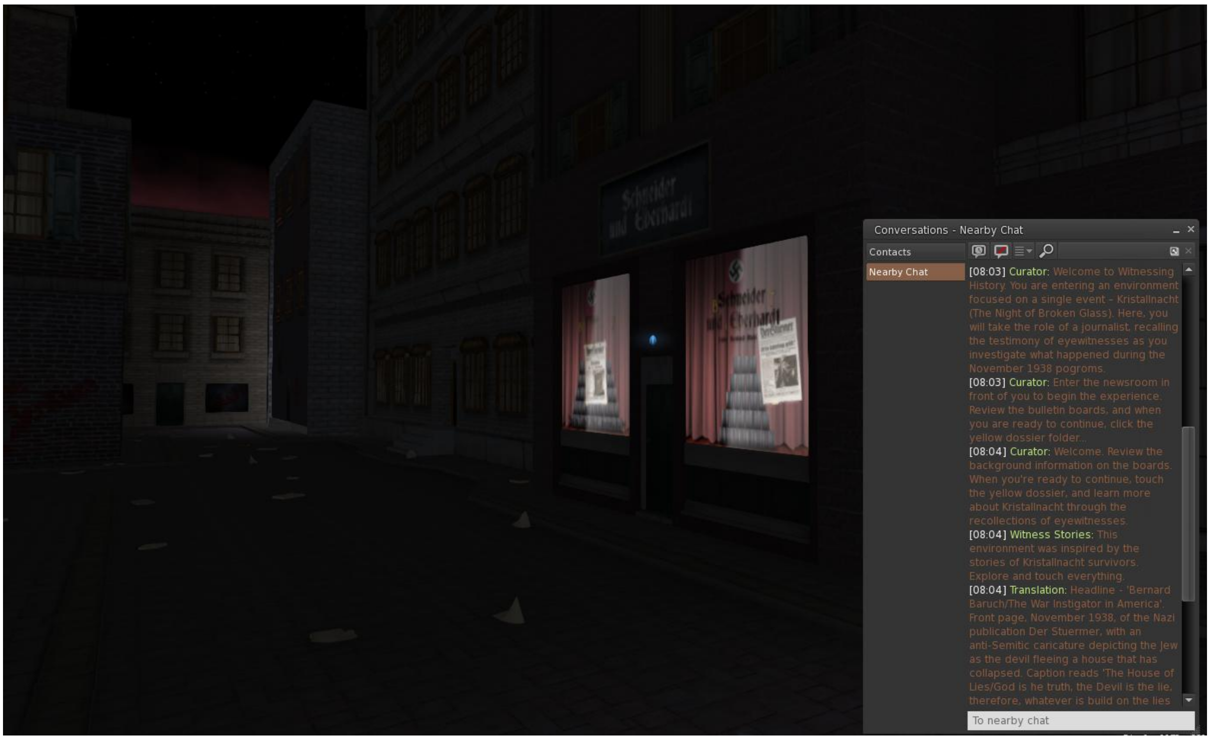


Figure 1: Witnessing History: Kristallnacht, the 1938 Pogroms screenshot

Virtual museum exhibits are popular in metaverse environments, with alternative digital platforms also receiving interest in creating virtual exhibits to teach about the Holocaust. In 2023, a Holocaust Museum was added to *Fortnite* (Bernard, 2023),a battle-royale shooter game with tools for players to make their own virtual experiences and host them through the official servers. Players can then join these experiences and play them, either individually or in groups. An experience was created for Fortnite titled *Voices of the Forgotten*, which includes a museum complex for players to explore. Unlike the museum in *Second Life*, Voices of the Forgotten does not include prompts for the player or any interactable content, instead relying on wall-mounted displays of photographs to educate the viewer. The main novelty of this experience is less about the content and more due to its hosting; Fortnite was not historically designed to be used in this way, but the creation update allowed for the technology to be used for educational means rather than for the gratuitous violence for which it was designed. Voices of the Forgotten is not part of any academic studies and was instead a piece created by Luc Bernard, a vocal advocate of Holocaust Education who has frequently used computer games as a medium for leaning. This topic was further discussed in the article Fortnite's new in-game Holocaust Museum shows us a virtual future for education (Challenor, 2023).

Figure 2: "Voices of the Forgotten" screenshot

Bernard's previous work was *Light in the Darkness* (Bernard, 2022), a computer game that followed the lives of a Jewish family in Nazi occupied Paris. Over the course of the game, the player experiences the perspectives of different characters, beginning with life prior to the occupation and demonstrating the escalation of antisemitism as the Nazis take control of the city. Although the player interacts with the environment and other characters, they are not given any freedom to change the outcome of events or the ultimate ending of the game, which will always result in the family being forced to board a train with the implication that they are being sent to either a ghetto, a concentration camp or a death camp. *Light in the Darkness* was created by Bernard to be used as an educational resource for the Holocaust and to try to create a Holocaust-themed computer game in a way that was appropriate for the subject material. Written by Joan Salter, a child survivor of the Holocaust, the story of the game was crafted to be accurate toward the real events of the Nazi occupation and teach new audiences of how oppressive society became for Jewish citizens. The game was reported to be planned for use as part of a study in Primary schools of student interest in Holocaust education after playing the game (Brodsky, 2021), however there are currently no publications available on the outcomes of this study.

Figure 3: Light in the Darkness gameplay screenshot

2.8. Ethical considerations for developing an AR app for Holocaust Education

The Holocaust as a topic is one that is, by its nature, emotionally charged and must be handled with sensitivity. Whilst it is theoretically possible to develop any form of learning application to try to teach about it, care must be given to ensure that the subject matter is handled appropriately and taught in a manner that is respectful to the victims. This was explored further in the book Chapter Augmented Reality in Holocaust Museums and Memorials (Challenor & Ma, 2023). It is entirely possible for a well-intentioned learning experience to instead cause harm, for example the game *Playing History 2 – Slave Trade* (Serious Games Interactive, 2013) is an educational computer game designed for children to interact and learn with the Atlantic Slave Trade from the perspective of a young slave boy. The player follows a narrative experience that showcases various different elements of the slave trade in a fairly sanitised fashion suitable for children without excessively graphic content, including gameplay mechanics akin to a point-and-click adventure game along with some minigames. One of these minigames incited public outrage (Patrick Klepek, 2015) as the player was forced to play a Tetris style minigame with slaves in place of traditional tetronimo pieces to simulate the practice of Slave-Stacking; the process by which slavers sought to fit as many slaves as possible into ships to maximise their potential profits, regardless of how inhumane these conditions were. Although this minigame was intended as a child-friendly learning experience, the reception from the general public was that it was a very tactless and inappropriate way of approaching the topic and was subsequently patched out of the game. Despite this backlash being targeted toward education regarding the Atlantic Slave Trade instead of the Holocaust, it serves as a cautionary tale that even the best intended learning experiences can be received poorly if the content does not handle the subject matter appropriately and so must be kept in consideration when developing any application or a topic of a sensitive nature.

When approaching the development of an AR learning application for The Holocaust, the considerations can be divided into two categories; the content being displayed and the means by which the player interacts with it. The United States Holocaust Memorial Museum has provided educators with a comprehensive set of guidelines (United States Holocaust Memorial Museum, n.d.)for methods of approaching the Holocaust during teaching exercises that can be applied to any form of pedagogical methodology including digital mediums such as AR learning environments. These include explanations of the cultural factors that lead to the Holocaust, providing a clear definition for it, using concise answers to complex questions to avoid oversimplification, and to be precise with the use of language to ensure there is no distortion of any of the historical facts, which are appropriate guidelines for any teaching exercise. However, the guidelines also include advice for the emotional aspects of educating on the topic, such as avoiding any comparisons of pain between groups or individuals, avoiding romanticising any aspects of it, ensuring that the lives of individuals and families are presented rather than just blanket statistics which are dehumanizing, and the most important guidelines for technology-enhanced lesson content: making responsible methodological choices. The museum states that graphic material should only be used to the extent necessary to achieve the lesson objectives and should not be used inappropriately, images and texts should not be used to exploit the emotional vulnerability of students, the material should not have the potential to be misconstrued as disrespectful to the victims, and simulation exercises should be avoided at all costs to avoid the possibility of a learner departing from the learning experience with the false perception that they understand what it would have been like to experience the Holocaust as a victim of it. In an AR learning environment, it is possible to show any form of imagery imaginable but as per the guidelines, graphical content should not be used unless strictly necessary to complete the lesson objectives, simulation exercises should not be used, clarity and context must be provided for all learning content and the definition of the Holocaust should be conclusive.

Guidelines about the dangers of simulation exercises have been discussed by others aside from the United States Holocaust Memorial Museum as there are a range of concerns regarding this particular pedagogical practice. It was also addressed by Bathrick et al (2008) in their book on visualising the Holocaust, in which they addressed simulation exercises and the dangers they pose. The authors defined a process titled “Empathetic substitution”- the processes by which learners may correlate their acquired knowledge of the topic to a false sense of understanding of what it would have been like to have experienced an aspect of history themselves. This is always a concern when visualizing the Holocaust and Bathrick et al caution that any attempt to encourage it among students should be rightfully scrutinised due to the blatant disrespect it would demonstrate to the victims, however it is a process that many, particularly adolescents, will naively ponder without contemplating the ramifications of such a line of thought. Whilst pondering what one would do if they were in a historical situation, the persons view will be distorted by knowledge of major events and their outcomes; information which those living in such times would not have the luxury of knowing and thus could not inform their decisions around. The authors expressly state that there is a narrow line that exists between empathy for historical events and identification, a line that is a perpetual challenge for any educator as any learning experience must be prepared to have its content adjusted to make learners consider the perspectives of historical figures without attempting to superimpose themselves into the scenario. No explicit advice is provided on how to do this as the logistics will vary depending on the methodology employed, however the constant advice is that at no point during the learning exercise should the learner be encouraged to position themselves within the Holocaust, nor should they be encouraged to consider what they think what courses of action they would have taken if they had experienced it.

There are also guidelines that have been considered as part of broader study on the depiction of dark or distressing topics outside of the Holocaust, particularly in regard to computer-based media. Within the context of VR, Fisher & Schoemann (2018) discussed historical locations with dark histories where VR apps have been used to educate audiences on their subject matter, and the ethical ramifications of doing so. This is discussed in the context of "Dark Sites", or locations that are either museums, monuments, or places that still have on-going issues, such as sites of natural disasters and similar traumatic events, and how these invite Dark Tourism, or the attraction of visitors due to their traumatic content. The authors argue that exposing audiences to traumatic experiences does not result in positive behavioural change and instead may only desensitise users to the subject matter, and so realism and authenticity should not be the primary goal of a VR learning experience if the result is traumatising for the user. Fisher & Schoemann also outline a series of guidelines designed to inform the ethical development of future VR learning experiences. These include not intentionally causing misery, ensuring there is support for the user's emotional wellbeing, avoiding violence where it is present only for spectacle, not commodifying dark events, and acknowledging that users will never achieve a complete understanding of traumatic experiences through a VR experience alone, meaning this should not be the target goal of any future application. Whilst these were written for VR, they are applicable to AR as well and align with many of the guidelines established by the United States Holocaust Memorial Museum.

Whilst not directly Holocaust themed, the UNREST project (Unsettling Remembering and Social Cohesion in Transnational Europe) (2016) is also applicable here, particularly in relation to memory studies and the interpretation of dark history. Running from 2016 to 2019, UNREST positioned itself as a response to what it described as a growing tension between a consensual European memory narrative built around reconciliation and the rise of more confrontational nationalistic memory politics. In response, the project proposed a third approach termed agonistic memory (Bull & Hansen, 2016), described as a mode of remembrance that acknowledges political disagreement and difficult historical tensions as opportunities for emotional and ethical growth. The project combined theoretical work with empirical case studies and the creation/testing of cultural practices, including work on topics such as war museums (Berger et al., 2018) and mass grave exhumations (Ferrándiz, 2019) to explore how different modes of remembering operate in practice. In the context of this research, the studies performed as part of UNREST suggests that dark history should not always be presented through purely reconciliatory or simplified narratives but can instead be approached in ways that allow users to engage critically with conflict, dissonance and contested memory. This is particularly relevant to digital heritage and AR learning experiences and demonstrates that a balance must be struck between traumatising or intentionally shocking learners (United States Holocaust Memorial Museum, n.d.; Fisher & Schoemann, 2018) and overly sanitising the subject matter.

Representation of the victims of the Holocaust is another area that requires careful consideration when depicting them within AR. Comparative Literature theorist Hirsch (2001) examined this in her analysis of the Holocaust, wherein she coined the term "Postmemory" in relation to the print media graphic novel *Maus* (Spiegelman, n.d.), a concept by which visualisations of the Holocaust were presented by descendants of its survivors in unique ways that would not be possible without the insights provided by their parents. In the case of Maus, Spiegelman interviewed his father, Vladek Spielgelman, and contextualised his stories by depicting them in comic format with the Jewish people being depicted as mice and the Nazi's as cats, both of whom were anthropomorphised. This depiction of the Holocaust sits within unusual territory; if it were attempted by someone without personal connection to the Holocaust, it could be reasonably interpreted as an offensive attempt to visualise history in a manner that propagates derogatory stereotypes. For example, objections could be raised to someone depicting Jewish people as rodents, or it could be argued that the predator/prey dynamic in the visuals propagates the "led to the slaughter" myth (Shabbetai, 1963), however the context of the author is integral to the reading of this book as the immediate connection between Spiegelman and the Holocaust defines the lens through which audiences read the text on a meta level. This book is not an artistic rendition of the Holocaust with questionable use of visual metaphor to tell a compelling story; this book is a man's attempt to contextualise his father's trauma through a visual medium that it might be preserved and used to educate new audiences on the brutal reality of living through a genocide. It is with this understanding that Postmemory interpretations are granted a greater range of creative freedoms than would not be afforded to outside parties. Hirsch argued that the narrative in Postmemory depictions is controlled by the perspectives of secondary witnesses, resulting in the trauma of the era being communicated to the readers, but not imposed in them. As such, although Spiegelman was able to portray the Holocaust within this manner, it would not be appropriate for someone with no direct ties to the Holocaust to attempt to depict it in such a fashion.

Beyond the topic of the Holocaust, there are additional ethical considerations to be made for any form of digital reconstruction created for history and cultural heritage purposes. These were brought up by Thompson (2017) in a discussion on the legalities and ethics of digitised cultural heritage, which used the ancient city of Palmyra as a case study. As an ancient city, the site contains a significant amount of history including ruins from the Roman and Persian empires, however over time it has also been affected by subsidence, erosion, looting, and intentional destruction, making the city a desirable candidate for digital recreation in the name of preservation. Thompson argues that recreations in any capacity are affected by embedded assumptions, citing Gavin Hamilton's 1758 painting of Englishmen visiting the site as an example of how creators may be influenced by their own assumptions rather than producing an entirely accurate depiction of the subject matter.

They also state that photographs include inherent bias due to the ways in which photographers compose their shots and what subject matter is left out of frame, meaning that photography may also present an incomplete or partial view of historical content. Thompson further discusses how human figures are often absent from digital models, or are represented in simplistic and repeated ways, which is attributed to the lower budgets and development times often afforded to digital heritage projects when compared to commercial games. Their discussion also highlights how time itself is frequently neglected, with digitised heritage often presented only through simplified before-and-after comparisons, alongside the issue of selection bias regarding which sites are considered worthy of digital preservation. In addition, Thompson notes legal concerns surrounding digital heritage projects, particularly where copyright is typically granted to the creators of the digital reconstruction, despite the physical locations themselves often existing within the public domain. Thompson does not propose a definitive solution to these concerns, but instead offers several possible strategies drawn from prior studies, such as presenting digital heritage visualisations as the products of the artists who created them rather than as fully accurate reconstructions, and making the sources and information used in the recreation available alongside the visualisation itself. These are not concrete guidelines, nor do they form part of a broader framework, but they do offer a logical compromise by encouraging transparency about both the limitations of digital reconstruction and the sources used to inform it, rather than presenting such visualisations as unquestionable or absolute.

Furthermore, just as Thompson (2017) critiques Gavin Hamilton's artistic choices in his painting of Palmyra, it is also important to critique the role of the designer in a digitised learning environment. This was the focus of a study by Rouse (2019)who discussed the ethical design of interactive narrative experiences for cultural heritage through a series of community-based co-design case studies. Rouse argues that interactive narrative projects must account for the difficulties of telling other people's stories, along with addressing that the designer cannot act as an impartial facilitator, which Rouse states to be a myth. To avoid this, Rouse provided a set of tips (not guidelines) to assist with the creation of an interactive narrative experience, which are structured around the idea that a project will involve working with students to create the interactive narrative and do not all directly apply to an independent research project. However, of these tips, the important ones to discuss for this project include developing community partners to network and consult with, create a structure that benefits all stakeholders, implement a participatory or co-design process with them, ensure time is allocated for formal reflection throughout development, preparation for projects to be longer than initially expected and possibly even multi-year long. For a project themed around a topic of dark history such as the Holocaust, it is especially important to collaborate openly with stakeholders, such as museums, communities or even survivors to ensure that all the learning content is presented openly, accurately and without taking creative liberties on the delivery of all information to try to ensure the experience is as close to being impartial as possible, even if full impartiality is an ideal that may not be attainable.

2.9. Technical Implementation Methods for Augmented Reality

Implementation of AR requires consideration of several factors to determine the most appropriate method for the project to ensure full compliance with both the needs of the user, as well as the logistical feasibility for the intended application. This can include the hardware used to implement the AR solution (Further continued in Chapter 3) along with the software considerations for how the AR project will be achieved. Edwards-Stewart et al defined six different types of AR in their classification of AR (Edwards-Stewart et al., 2017) which they broke down into two categories: Triggered and View Based. The Trigger based are defined as follows:

1. Marker-based: AR that requires a marker (such as a QR code) to activate.
2. Location-based: AR that uses the GPS function of the hardware to trigger AR at pre-defined locations.
3. Dynamic Augmentation: AR that is responsive to the view of an object. The provided example for this is a shopping application that allows users to "try on" clothing or accessories by using AR to overlay them with the user.
4. Complex Augmentation: A combination of the prior types that can use markers, location and dynamic triggers for varying purposes. The provided example is the now discontinued Google Glass, which could utilise GPS positioning along with dynamically targeting objects within the user's vision to display additional information.

Alternatively, the View Based forms of AR are defined as such:

1. Indirect Augmentation: AR that augments a static view of the world that often includes augmented images. The example for this provided is one that allows users to take a photograph of a room and then change the wall colour, with the ability for the application to identify the wall, isolate it and only augment that element of the photograph.
2. Non-Specific Digital Augmentation: AR that digitises a dynamic view of the users' surroundings but does not reference it directly. This example is described to be most common in mobile games, in which AR content may be visualised on the users' surroundings but plays no role in the use of the application itself.

These categories, although somewhat broad, are useful indicators of different methodologies that can be employed to design an AR experience, along with categories prior studies to identify the strengths and weaknesses of each method.

2.9.1 Trigger-Based AR: Markers

Learning experiences built with triggers have been one of the longest-serving methods of AR implementation due to the processing power required to utilise this method and have been successfully deployed to a range of devices. One of the first instances of this was introduced by State et al as far back as 1996 (State et al., 1996). The authors of this paper introduced a method of using "Landmarks" – a pre-cursor term for fiducial markers, as a method of targeting for both triggering and positioning AR content. State et al designed their markers to use a combination of colours, dots and rings for a combination of twelve different markers. As a proof-of-concept study, the focus of this paper was regarding the mathematics required to facilitate the AR tracking method rather than the outcomes of its usage, however this study was the progenitor of all future marker-based AR applications and subsequent research.

Future projects continued to develop on this method of utilising AR and expanded upon the types of markers that could be used, along with the technology that could be utilised for rendering AR. For example, in 2010, ConnectED developed an application named *Second Sight* (McElroy, 2010) for the PlayStation Portable, an application that could utilise the devices external camera peripheral attachment to detect QR Codes and use them as a trigger for rendering AR content on the device. This method of rendering AR utilised the graphical rendering capabilities of a hand-held games console and bypassed the need for bespoke hardware, instead only requiring applications to be developed for it that could utilise the *Second Sight* AR Framework. Although demonstrated as a proof of concept, it is unclear if *Second Sight* was ever utilised for AR learning experiences due to a lack of publication on it.

Despite this, there have been alternative studies performed into using trigger-based AR with markers as the logistical method of their projects. An example of this would be a study by Paliokas et al (2020) who used markers placed inside of museum exhibits to facilitate the usage of an AR application. This study sought to utilise AR to provide an application for visitors to download on their smartphones that would allow them to both navigate the Silversmithing Museum in Ioannina, Greece, which was later dubbed the "E-Tracer" application. The authors created small images of the artefacts inside the display cases with the museums artefacts which were used as the marker for the application to identify and subsequently provide additional information on, a solution that the authors claim audience would find "aesthetically acceptable". This functioned for the purposes of the application, however the authors did note that this was not a perfect solution as complications can arise when utilising marker-based solutions, such as humans not being able to identify some marker solutions such as QR codes, along with the readability of markers being variable depending on the lighting solutions within their placement area. The prior point is possibly mitigatable by providing context regarding the aesthetic configuration of markers to readers prior to their usage of the application, however the point regarding marker readability is of specific concern if the lighting conditions of the display area are dark or variable, either of which could have a negative impact on user ability to interface with the AR application.

A similar methodology was employed by Jevremovic & Petrovski (2012) in an earlier study on trigger-based AR. This application was built for the National Museum of Serbia, a museum that, at the time of the study's publication, had been closed to the public for a decade and thus rendering the contents of its exhibits inaccessible to the public. In an attempt to make the contents of the museum accessible despite the physical building being closed, the authors of the study developed an AR application with information regarding some of the artefacts within the museum and placed them outside of the building and invited participants to download the application to use. The authors organised a social movement for participants to download this application and interact with the AR content on the doorstep of the Museum in what the authors subbed "Street guerilla action". The purpose of this study mostly seemed to be to instigate a social movement into making the history of Serbia more accessible to its citizens rather than to further develop the medium of AR, but the authors did indicate that museums and other learning centres would need to become socially conscious of the requirement to adapt learning methodologies to fit with the digital era and the expectations of learners from technically-oriented generations.

Generational approaches toward technology and technology-enhanced-learning have been a point of interest for both the AR and the TEL mediums. This was further explored in another marker-based study on the engagement of users in museum spaces by Pérez-Sanagustín et al (Pérez-Sanagustín et al., 2016). This study did not provide context regarding the tools used to develop their and only mentions that participants used their own smartphone devices, with no AR being utilised in this study. Rather than purely exploring AR, the aim of this study was to further explore audience engagement with QR codes in museum spaces. Operating at the Princess of Wales Conservatory, the authors sought to integrate both digital screens and QR codes alongside the various exhibits to provide visitors alternative means of learning about the various plants at the facility. The results of this study were found not to be statistically significant; however the authors did identify several trends from their data:

1. Participants spent more time-consuming information at an exhibit when provided with a screen, and that they were again more likely to consume information when provided with audiovisual information via a QR code.
2. QR codes did not affect visitor experiences with exhibits (this is clarified as participants experience was not negative as a result of using QR codes).
3. Participants spent more time engaging with exhibits when QR codes had an interactive or social element to them.
4. Adoption rates of QR codes was higher among college age students than older age groups, however the authors acknowledge that their sample range of ages was not high enough to statistically quantify this trend.

Results from this study indicate that audiences are willing to engage with new forms of information delivery and, although not necessarily an AR study, the technology used is engaging for learners in a fashion that could be used in AR based studies without detriment to audience experience. It also suggests that technology-based learning mediums may have higher adoption rates with younger audiences, although the learning outcomes for each age group were not presented, leaving uncertainty to whether there may still be pedagogical benefit for older audiences even if interest in such systems is lower.

2.9.2 Trigger Based AR: Locations

Location-based AR is a result of progressive iterations of AR to utilise additional technological developments to further expand upon the medium, allowing users to trigger augmented content with their physical location in the real-world rather than relying on markers or symbols. As such, studies have experimented with its implementation to identify ways in which it can be used for educational purposes. An example of this is a study by Chang et al (2015a) that used location-based AR to create a guided tour of the Tamsui District of New Taipei City in Taiwan. The authors built two location-based AR applications: the first had full AR capabilities and could be used to augment buildings to provide additional information to them, and the second functioned similarly but only provided audio content without any visual augmentation. These applications were tested on three groups, a control group with no AR, and a group for each application. When tested, the group with the full AR application had more knowledge of the city and reported a higher emotional response, with the Audio and control groups reporting comparable results for emotional responses but a lower rate of knowledge than the control group. This study demonstrates that AR has potential as a resource not only for learning knowledge, but contextualising history and giving users a better sense of attachment to it.

Location-based AR is still contextual depending on where it is implemented, however other studies have demonstrated that it can be used to create a sense of attachment for from a user to physical locations. This was shown in a study by Oleksy & Wnuk (2017) on the use of the location-based AR game *Pokémon Go* (Niantic, 2016) and how it could be used to increase the sense of attachment to a location, specifically locations that are not directly linked to the contents of the game. This study was performed online and recruited participants using social media, who were then surveyed on their attitudes toward locations when playing the game and also asked users to provide their opinions on experiences when playing the game. Results found that participants foster place-attachment only when experiencing either positive experiences within the game, or positive social contact as a result of the game. Whilst this is encouraging, the results were entirely dependent on organic gameplay and social experiences occurring independently from the application.

By contrast, other studies have sought to utilise a specific and pre-determined locations as a focal point for AR studies to further explore how the use of an exact environment can be used as part of a learning experience. For example, Pacheco et al (2015) sought to use AR to create a guided tour of the Bergen-Belsen Memorial, a location that was once a Holocaust-Era concentration camp but has since been destroyed. The authors created an AR application using a tablet device to virtually reconstruct the camp using historical datasets, using GPS-based location data to position the augmented content. This project, although it utilised location-based triggers, was built as a proof-of-concept rather than an in-depth academic study, however it did conduct research on the spatial memory of participants. Participants were divided into two groups; the first was given free reign to explore using the application, the other was given a guided tour with it and both were tested afterward. It was found that the group allowed to explore freely had attained better spatial memory of the locations than those with the guided tour, which suggests that although usage of AR can be effective for re-creating historical learning experiences, the freedom of exploration is also a vital component to for learning.

Additionally, other studies have further explored the use of physical locations as triggers for AR, such as research performed by Harley et al (2016a) on the Roddick Gates in Montreal, Canada. The authors developed a mobile application to be used at the Gates that could augment the gates with visual information from how they looked during the 19^{th} century. Participants, all students at McGill

University, walk past these gates daily as they serve as the entrance to the campus. The study tested for both how many differences the participants were able to identify between the two eras, along with their emotional responses to the experience. The study found that participants were able to successfully identify most of the differences and also that they had enjoyed the experience, along with the collection of some student responses. One student expressed that it had given them a new perspective of the landmark, some others expressed that they had been bored by it. Opinions will be contextual depending on the location and the perspective of the user and as such may not be a quantifiable metric to be applied to all location-based AR experiences, however it does demonstrate that location-based AR can provide additional context and information to physical locations in a manner that can be enjoyable for users.

Although educational learning experiences are primarily the focus of this thesis, some academics have also sort to incorporate gameplay elements as part of their applications to provide entertainment factor to users along with having additional appeal to younger audiences. This was the case with a study by Herbst et al (2008a) in which the authors created an AR game called *Timewarp*, an application that would allow users to interact with a group of virtual elf characters when exploring the city of Cologne, Germany. The emphasis of this application was to educate users on buildings that no longer exist by using AR, with users interacting with the virtual characters and a range of minigames, puzzles and item location challenges. This study did not publish results from experimentation and served as a technical investigation of the matter, with the authors reporting that although the application functioned, the GPS was often unstable which would result in objects moving around, or that sunshine was impacting the ability to render locational objects. These concerns may be present in future iterations of location-based AR projects; however it is important to identify that this study was conducted in 2008 and as such, the hardware used to achieve both GPS tracking and AR rendering are extremely outdated by today's standards and modern devices may not suffer these issues, or not to the same extent.

2.9.3 Dynamic Augmentation

Dynamic Augmentation is seldom the desired methodology of studies relating to education, with many of its applications being used for commercial uses. For example, several Makeup companies utilise a Dynamic Augmentation solution called *Perfect Makeup AR* (Perfect, 2024), an application that allows consumers to scan a products barcode on their mobile devices, which will then use their front camera to read their faces and preview the makeup on them and allowing them to virtually "sample" the tone before committing to a purchase. This was also explored in a technical study by Sekhavat, (2017) who built an AR framework that would allow users to digitally try on clothing by creating a 3d model of themselves and then scanning an AR tag on an article of clothing in a store, which would then create a preview of how the person would look when wearing that item of clothing. Whilst these both demonstrate use-cases for the technology, it is highly contextual in its usage as it relies on a physical object that would benefit from AR enhancement being rendered over it. Consequently, there are no appropriate cases of it in literature that can be used as prior examples of this technology in use for educational purposes.

2.9.4 Complex Augmentation

Although Complex Augmentation was defined as a method of triggering AR by Edwards-Stewart et al (2017), the definition is broad and only applies to AR that seeks to synergise its triggering mechanisms rather than utilise an individual one. When exploring existing literature on AR, it is difficult to find examples of academic study that have specifically aimed to achieve this, with studies generally option toward using a very specific triggering mechanism. Consequently, it has not been possible to identify literature that expands on this concept further at this time, however future studies may see additional development in this area.

2.10. Summary

Within the context of this literature review, the sources examined have demonstrated existing works that contribute toward the research questions, but do not answer them. Consequently, there is still room for further academic exploration into these topics to better inform future educational epistemology. This can be better structured by examining how this literature pertains to each research question, along with addressing the ethical considerations behind the creation of such a project.

2.10.1 What Impact Does Augmented Reality Have on Long-Term Memory Retention Compared to a Classroom Learning Experience?

Studies have explored the topic of AR for memory retention in the past, with studies aiming from retention periods of immediate (Cook, 2019a; Sommerauer & Müller, 2014; Chang et al., 2015a), two weeks (Menon et al., 2022a; Zhang et al., 2022a) , to four weeks (Billinghurst & Duenser, 2012a), and generally found that the use of AR correlated to higher rates of memory retention than traditional methods. There do not appear to be any studies exploring the impact of this on longer periods than four weeks, which is somewhat inconsequential within a learning environment, particularly when considering that learners can be presented with information months or entire academic years prior to exam periods. The technology does appear to be beneficial toward immediate learning outcomes and studies on learning groups have found that participants can demonstrate higher rates of learning performance when using AR (Zhang et al., 2022a; Cook, 2019a; Menon et al., 2022a; Billinghurst & Duenser, 2012a; Yoon & Kang, 2021a; Wu et al., 2013a) which suggests that the use of the technology does stimulate additional cognitive development within learners who engage with AR systems, however there is insufficient data to determine if the technology maintains a notable rate of increased retention over a prolonged period of time.

2.10.2 Does the Technology used to Implement Augmented Reality impact how much information Is retained? (Handheld vs Head Mounted)

Studies that have explored the topic of AR for memory retention have all sought to use an AR focus group as part of their testing methodology, but none appear to have performed a direct comparison of head-mounted against handheld devices. Furthermore, handheld devices do appear to be the preferential device for such testing, with multiple studies exploring the use of AR apps for smart devices or other bespoke handheld hardware (Billinghurst & Duenser, 2012a; Cook, 2019a; Sommerauer & Müller, 2014; Yoon & Kang, 2021a; Zhang et al., 2022a) rather than head-mounted options (Menon et al., 2022a) and with datasets that only serve to demonstrate that focus groups perform better than control groups. Furthermore, across the field of research of AR for educational purposes, HMDs do tend to appear in fewer studies than handheld devices, with this literature review only identifying a few studies (Menon et al., 2022a; Jin et al., 2020; Kaghat et al., 2020; Kyriakou & Hermon, 2019) that did opt to use a HMD. The limited data available here demonstrates that additional research is required to answer this question.

2.10.3 Does the Location of the learner have any impact on the amount of information they retain? (Classroom vs Museum environments)

Similar to studies on implementation methodology, studies that have sought to identify learning trends using AR will often have a specific location for the study, such as a classroom or a museum, however none of these studies are seeking to test the use of the technology in multiple locations. Most tend to favour classroom environments (Billinghurst & Duenser, 2012a; Cook, 2019a; Menon et al., 2022a; Yoon & Kang, 2021a; Zhang et al., 2022a) with little knowledge retention study in museum environments (Sommerauer & Müller, 2014; Kaghat et al., 2020). Museum environments are still an actively utilised environment for AR research, however the studies performed in them tend to explore other areas of the technology, such as AR for narrative and historical purposes (Jin et al., 2020; Ma et al., 2017; Takahashi Dean, 2018; Keil et al., 2011a) , technical investigations into the hardware (Kyriakou & Hermon, 2019; Falomo Bernarduzzi et al., 2021b; Boboc et al., 2019), creating proofs of concept for more advanced logistical projects (Stapleton & Davies, 2011b; Ulaby, 2022), investigations into user satisfaction(Kaghat et al., 2020), how society values the technology (tom Dieck & Jung, 2017) and even accessibility considerations (Ahmetovic et al., 2021). Demonstrably, there is continued academic interest in utilising both classrooms and museums as locations for AR research, however there is no data to investigate the efficacy of utilising the hardware for sustained learning outcomes that compares these two, especially against a control group. Therefore, additional research is required to answer this question.

2.10.4 Does the age of the participant impact the amount of information retained?

This question is one that holds the least amount of academic data due to the nature of how studies on AR are typically performed with regard to information retention. Many AR apps for educational environments are built specifically for younger audiences, for example school-age children (Cook, 2019a; Billinghurst & Duenser, 2012a), university students (Zhang et al., 2022a; Yoon & Kang, 2021a), medical students (Menon et al., 2022a) and in limited cases, adults (Sommerauer & Müller, 2014). In the case of the study performed on adults, the age ranges of participants were between 14 to a maximum of 79, however the effect of participant age upon the outcome was not a part of that experiment. Despite museum and heritage sites having the potential of educating adult audiences using AR technology, the effect of it has not been examined or statistically analysed to identify if the technology provides lasting benefit for adult audiences. Because of that, this research question has not yet been answered and so there is potential for academic benefit in further exploring it.

2.10.5 What are the ethical considerations for creating a digitised learning experience based around dark history?

Developing a digitised learning experience covering dark history must ensure consideration is given to the subject matter and any guidelines established by leading bodies in their subject matter area (United States Holocaust Memorial Museum, n.d.). Furthermore, audiences for the experience must be positioned as outside observers of the topic rather than as someone living through it to prevent empathetic substitution (Bathrick et al., 2008), and care should be taken to avoid intentionally distressing the learner or attempting to communicate a complete understanding of trauma (Fisher & Schoemann, 2018). Creative liberties regarding how dark history is communicated are very context specific and should generally be avoided unless the creator of the learning experience has personal and direct links to the topic to avoid perpetuating offensive stereotypes (Hirsch, 2001b; Spiegelman, n.d.). When developing a digital learning experience for dark history, the developer should be transparent with the origin of the information and communicate that the visualisation is presented as a product of the creator rather than an accurate rendition of history (Thompson, 2017). Any information being presented in the experience should be sourced from stakeholders, be subject to collaborative design and iteration, and communicated as accurately as possible for the creator to attempt to remain as impartial as possible (Rouse, 2019).

2.10.6 What design considerations need to be made for digital heritage learning experiences?

When developing a game-based project themed around history, two models can be used for gameplay interactions, realist simulation or conceptual simulation (Chapman, 2016), however in the context of digital heritage, realist simulation is the approach that better aligns with presenting facts and information rather than attempting to take creative liberties, which is best avoided when addressing dark history (Thompson, 2017; Rouse, 2019; Barbara et al., 2022), even if players generally tolerate deviations from accuracy in the name of an authentic feeling experience (Copplestone, 2017). If gameplay elements are to be included, the digitised elements should follow the Historical Problem Space Framework to simulate history both with environmental pieces and build gameplay strategies designed around historical constraints (McCall, 2020), however the first principle of this framework also requires the player to be represent a historical actor, which should be avoided in the cases of dark history (Bathrick et al., 2008; Fisher & Schoemann, 2018; United States Holocaust Memorial Museum, n.d.). Any project built for digital heritage should be designed with sustainability as a priority to ensure the project can be adapted to new hardware or emulated so that it can be used into the future and not deprecate with time to become lost media (Denard et al., 2009; McCall, 2023). The design of the project should facilitate a playcentric design process (Fullerton et al., 2008), in which the design is iterated on frequently to ensure the application is engaging for users and that there is a definitive relationship between actions taken by the player and their outcomes (Tekinbaş & Zimmerman, 2003) to assist with fostering meaningful engagement (Sicart, 2014). Where possible within the context of design, learners should be able to repeat sections of the experience as required when they desire to, without needing the entire game to be replayed to ensure they can reinforce understanding (Wolf, 2002). Lastly, any visualisation should only be created where it offers a meaningful contribution to the interpretation, communication, or preservation of history that would not be as effectively achieved through alternative methods (Denard et al., 2009; Barbara et al., 2022).

2.10.7 Justification for developing an AR application

The implementation of an AR application is justified in this project because it provides a means of preserving and communicating Holocaust testimonies in a form that is both sustainable and meaningfully tied to an existing museum. As Denard et al. (2009)argue through the London Charter, digital visualisation should be used where it offers a meaningful contribution that cannot be achieved as effectively through alternative methods, which is applicable here as AR provides a way to preserve survivor stories for future learners at a time when the remaining Kindertransport survivors are now very elderly, meaning that opportunities for direct first hand testimony are increasingly limited and ultimately finite. Furthermore, this approach is meaningfully tied to the National Holocaust Centre and Museum, a location that already supports learning and survivor testimony, which allows AR to provide additional opportunities to present information in ways that synergise with the exhibit content already situated within the museum. Existing research supports this with suggestions that AR content can support engagement and learning when designed appropriately (Billinghurst & Duenser, 2012b; Cook, 2019b; Menon et al., 2022b; Wu et al., 2013b; Yoon & Kang, 2021b; Zhang et al., 2022b), whilst heritage focused studies emphasise that AR content must remain grounded in the physical environment rather than distracting from it (Haahr, 2018; Dionisio et al., 2016). At the same time, work on dark history and digital heritage states that these experiences must be created with caution, transparency, sensitivity to those being depicted, whilst also avoiding spectacle, sanitisation or inappropriate gamification (United States Holocaust Memorial Museum, n.d.; Fisher & Schoemann, 2018; Thompson, 2017; Rouse, 2019; Barbara et al., 2022). Consequently, the use of AR is justified here as it is a responsible visualisation tool that can preserve testimonies, situate learning within a meaningful space and support future engagement with Holocaust history in a way that is both accessible and ethically accountable.

Based upon the trends and current knowledge identified within this literature review, all four research questions may be viably explored within this thesis and offer the potential to provide a novel contribution to future research and the AR research community. In addition, the literature reviewed has also established a broader ethical and design framework for the creation of a digital heritage learning experience, particularly in relation to dark history, historical accuracy, stakeholder involvement, and sustainable implementation. Consequently, these four research questions will be the focus of this study, alongside the technological implementation required to do so, which will be the focus of the following chapter.

3. Methodology

3.1. Testing Methodology

The research questions (Specifically the questions regarding the efficacy of the technical implantation of AR and the locations of the user) required multiple different implementations of both technology and testing locations to provide the required data. This would involve building two different applications with varying implementations of AR technology that would be suitable for deployment in different locations without detriment to the user.

The primary application required a suitable AR implementation method with a Head-Mounted device to provide a modern approach toward interacting with augmented content. The second would need to be an alternative that utilised a different form of hardware in order to provide a varying interaction method with the same form of AR learning content.

3.2. AR Application Development Considerations

The original plans for the application were structured around the National Holocaust Centre & Museum's exhibit of The Journey (The National Holocaust Centre and Museum, n.d.), an exhibit structured around a proxy character named Leo who is a fictional Jewish boy living in Germany during the rise of the Nazi regime in the 1930s. The exhibit contains storytelling displays through several rooms, all modelled after different places within Leo's life, along with a projector and touchscreen to provide some interactive video media for audiences. Initial designs for the project were themed around creating a narrative experience that would further expand on Leo's story to provide new context and learning experiences for museum visitors to further expand their understanding of the emotional aspect of the Holocaust. However, further discussions with the Museum refined the project away from a narrative experience, such as the one created by Jin et al (Jin et al., 2020) in favour of an application that could expand on factual knowledge of real artefacts and use AR technology to digitally preserve stories and experiences of real-world Holocaust Survivors.

Within the logistics of the application design, this would require additional consideration for the structure of the application and how AR would be utilised to best provide both rendering and control to the users. Referring to the Edwards-Stewart (Edwards-Stewart et al., 2017) classification model, multiple methodologies needed exploring to identify a solution amenable to both AR implementation methods along with the varying locations the application would need to be deployed at.

3.2.1 Trigger: Marker Based

Marker based methods of AR utilise a Fiducial Marker (Craig, 2013) such as a QR code or an image to act as the target location for augmented content to trigger, often used as the anchor point with which to render the content over. This provides a great deal of freedom and flexibility to the application designer as the project can be feasibly upscaled to include new content as required, with new content only requiring a change of marker or the creation of a new one. Logistically, this requires codes to be created and then physically placed within the exhibit at the required locations for the content to trigger (Paliokas et al., 2020; Jevremovic & Petrovski, 2012) which, whilst controllable, would require additional considerations for deployment at both the Museum and any alternative testing environments due to potential lighting and physical object variations that could impact the ability of a marker to be read, or the physical requirements of where one could be placed. Despite this, a prototype was constructed utilising markers as a proof of concept.

Figure 4: Fiducial-Marker Prototype

The AR-Plugin tool (UPLUGINS, 2018) for Unreal Engine 4 was utilised to develop a prototype application for Android devices that could utilise Fiducial Markers to trigger AR rendering using the codes as both a trigger and an anchor point for the 3D content. This was built in Unreal Engine 4.19 with Android devices as the target source, with a 2018 Samsung Galaxy Tab A (Samsung, 2018) tablet device as the chosen device to run the application. The Samsung Galaxy Tab A was selected as it featured a camera (which was necessary for scanning markers) along with an octa-core 1.8ghz processor and 3gb of RAM, ensuring it was powerful enough to run an AR application without concerns for performance from the hardware. Furthermore, the Samsung Galaxy Tab A also natively ran Android version 8.1, ensuring that it was compatible with all Unreal Engine functionality for Android as of Unreal 4.19. Initial prototyping made use of the default content included with the AR-Plugin tool, including the marker mapping and the 3d model of a motorcycle.

The AR-Plugin tool provided much of the core technology, however it did come with several limitations. Firstly, the tool was incapable of using multiple triggers simultaneously; if multiple markers were detected then they would all activate, however they would position the 3D objects at the last trigger read, resulting in multiple objects stacking on top of each other in an aesthetically unpleasant manner. Secondly, the tool required each marker to be black and white with a thick black border around each marker, resulting in limited possible variety for markers along with no consideration toward the aesthetic requirements of the museum, or any other location where the application may be deployed. Due to these factors, the AR-Plugin method was rejected in favour of exploring alternative options.

An alternative application that was explored was Vuforia (2024) for Unity, the same technology used by Roopa et al in their AR study (Roopa et al., 2020) and a long-standing framework for Unity-based AR applications. Unlike the constraints imposed by AR-Plugin for the Unreal Engine, Vuforia is capable of using images as targets rather than thick-borders, resulting in a broader range of targets available for triggering AR rendering and interactions. Although this allowed for additional possibilities, Vuforia also includes some requirements for how markers must be constructed for the framework to recognise them, including the overall contrast range; Vuforia converts all targets to greyscale and relies on the contrast between values to read the image. If an image does not have a sufficient contrast range, the system may be unable to read the code. This problem may also be exacerbated by the concerns raised by Paliokas et al (2020) that a low-contrast range image target, combined with low lighting levels in the users environment, may be completely unreadable by the system.

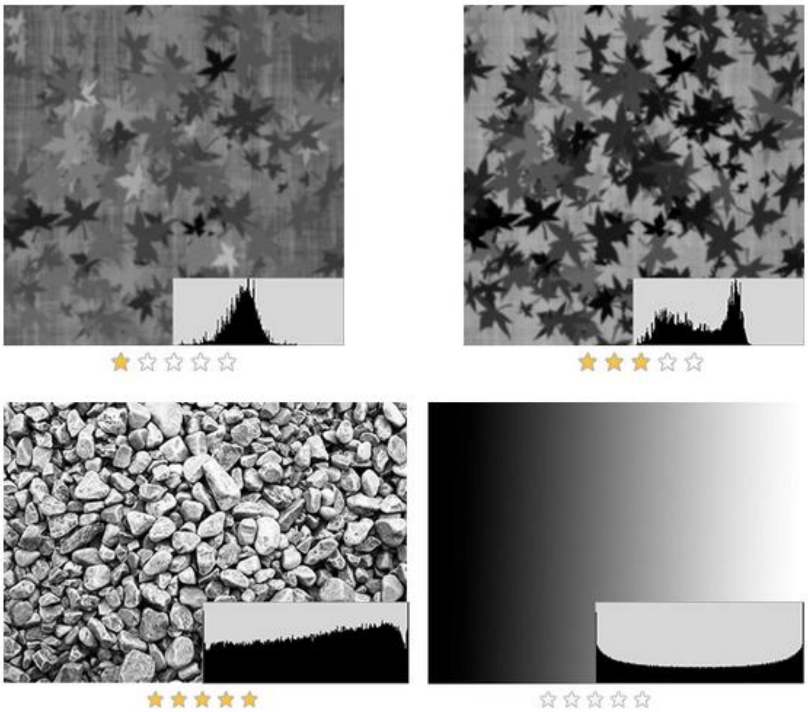


Figure 5: Vuforia Example Contrast Ranges & Ratings

After conferring on methodology, markers were ultimately ruled out as a solution for this project. Primarily, The Journey exhibit is designed to accurately replicate a series of environments with historical accuracy including vintage furnishings and decorations, imposing QR codes or an alternative form of marker upon this would detriment the aesthetics of the exhibit (Paliokas et al., 2020) and provide a potential distraction from the main purpose of the exhibit, which is to teach schoolchildren with no use of AR technology. Secondarily, the use of markers may cause some complications with the scope of the project; the purpose of the application was to provide information and context regarding a large range of artefacts, each of which would require a unique marker. Consequently, this would inevitably saturate the exhibit with markers and possibly causing logistical complications for their dispersion and for users to locate/target them. Lastly, the use of markers has long been a method of controlling AR scenes dating back to 1996 (State et al., 1996), consequently resulting in less novelty for future studies built on an aging methodology, along with a reduced range of research topics that can do more than iterate upon prior research. Due to these reasons, alternative forms of AR were instead explored.

3.2.2 Head-Mounted Device Considerations

Initially the proposed plan for the project was to utilise a Microsoft HoloLens (Microsoft, 2021a). At the time of production, the 2nd Generation HoloLens (Microsoft, 2022a) was in development with an approximate release date of May 2019 which fell within the scope of the development period of the project. The plan as proposed was to begin development on the first-generation HoloLens and transition into using the 2nd Generation version upon release as part of exploratory research into the expanded capabilities of the newer hardware, however the release date was later delayed to November 2019 (Hanson, 2019). Additionally, acquisition of 2nd Generation HoloLens devices was further impacted by a mass-purchase by the United States Army (Humphries, 2021) that ultimately delayed consumer access to the devices. This rendered the 2nd Generation HoloLens unsuitable for the project by virtue of availability; it was not ascertainable if it would be possible to acquire a device within the scope of the project. Regarding the 1st generation HoloLens, two of these devices were available to the researchers at the University of Staffordshire, which rendered them available for the project. This version, although older, had the rendering capabilities to project AR content over a scene and allowed the user a limited range of controls, primarily consisting of a hand gesture, voice controls and head-motions, which were not as expansive as may have been desired but would be suitable for creating an AR learning environment.

Alternatively, the Project North Star (Ultraleap, n.d.) was considered. As an open-sourced project, the Project North Star (Henceforth abbreviated to PNS) was initially construct by the Ultraleap team as a community-driven alternative to commercial AR devices. Due to the nature of the device, it is not limited to a single design; users have the capacity (and the encouragement of its developer community) to re-design the device to suit their own requirements, for example adding in an additional ranges of sensors, screens, peripherals or any other devices desired. The benefits of this are that the device can be altered as required to create a bespoke experience, and also that the cost of the device is relatively low considering that many of the required components were commercially available at competitive rates, with news outlets reporting that the device could be built for under one hundred US dollars (Wong, 2018) ($122 adjusted for inflation, or £97.55 in GBP). Despite these advantages, there are problems with the PNS; the device is not sold, it needs to be constructed by each individual user which adds the complication that users must be at least somewhat knowledgeable in hardware principles to build the device, along with access to the necessary tools. As a community-sourced device, it does not have any official developer support available aside from a community discord server, meaning that any complications encountered during construction, application development or usage must be troubleshooted by the user, or at the mercy of the discord server community to assist rather than an official channel. Due to the experimental nature of the hardware and the inconsistent support available, the PNS was ultimately not chosen for this project.

Another device considered was the Varjo XR-1 (Varjo, n.d.) headset. The XR-1 headset is an AR headset with a much broader range of features than a HoloLens, for example the visor has a much broader field of view (further abbreviated to FOV) than other competing headsets at 87 degrees (compared to the 1st Generation HoloLens of 30 degrees) along with eye tracking, High Dynamic Range (further abbreviated to HDR) colour rendering and a physical stylus peripheral for the user to interface with. Despite the advanced capabilities of the device, it is not a truly mobile device, with a desktop PC being required to use it and a physical cable that must be tethered at all times. Furthermore, the XR-1 has a price cost of $9995 US Dollars. Due to its relatively high cost of $10,000 at the time of the study, this equipment was beyond the budget of our research.. Consequently, due to these factors and the logistics of transporting a desktop PC to use the device, the XR-1 was not pursued for this project.

Alternatively, the Magic Leap 1 (first generation) (Magic Leap, 2019) was a possible alternative considered. Although described by the developers as "something between AR and VR" (Justin_tech, 2019), the Magic Leap 1 is a standard AR headset that was a proposed market competitor to the Microsoft HoloLens. The Magic Leap 1 had a broader FOV than the HoloLens 1st Generation (40 degrees) and a spatial controller for the user to hold that could facilitate interfacing with the device. Despite these features, reviewers of the hardware unfavourably compared the device to the HoloLens 1st Generation (Robertson, 2018; Justin_tech, 2019) with comments regarding the rendering capabilities and performance of the device suggesting that it was not as powerful nor as consistent. Because the HoloLens 1st Generation was reviewed as a superior product with more consistent performance, and with the Magic Leap not offering any alternative features that could potentially benefit the project, it was ruled out as a choice.

Lastly, the Google Cardboard (Google, n.d.) was the final HMD implementation considered for the project. Designed as a cost-effective solution for AR and VR developers, the Google Cardboard was a simple cardboard HMD with lenses and a slot for the user to insert a smartphone device. All of the physical hardware was contained inside the users smartphone, with the Cardboard being used as a means to convert it into a HMD. Whilst this was an interesting consideration to make, there were several stipulations involved with it. Firstly, any application developed for it would be constrained by the rendering limitations of the mobile device used which shifts the development concerns from HMD to those of the mobile device. Secondly, modern mobile devices are typically controlled with touchscreens rather than external peripherals, which would limit potential control schemes. Finally, any technical exploration of this configuration could be argued as an exploration of the bounds of mobile devices rather than standalone HMDs, which could possibly skew interpretations of the methodology or data collected. Although the Cardboard presented some interesting technical logistics, it was decided against in favour of a standalone HMD.

3.2.3 Mobile Device Considerations

The mobile device build required several pre-requisites for device consideration. These are as follows:

1. A built-in rear camera for AR visualisation.
2. Graphical rendering capabilities powerful enough to support AR applications without significant performance impact.
3. Touchscreen capabilities for user inputs. These are the current standard for mobile devices, resulting in users already having some basic operational knowledge that would not require additional training.
4. A screen large enough for users to clearly see and interact with. This is not a limiting factor for most devices as screen sizes are relatively consistent between various manufacturers, with technology news site The Verge estimating that consumers consider 6.1 inches to be the ideal screen size (Johnson, 2022). This does however rule out any small devices (Below five inches) as this would potentially impair the design of the interface, along with possible causing difficulties for users with visual impairments.

A series of devices were explored as potential viable candidates for this project. With the market being saturated with devices of similar specifications, there was no limitation of available choices, however a single device was required to ensure consistent performance across participant testing.

The first devices explored was the iPhone 12, a device with a 6.1 inch display, a rear facing 12 megapixel camera and a quad-core GPU for graphical rendering (Apple, 2020). iPhones are a popular mobile device in the UK with an adoption rate of 52% (Sherif, 2024) . The functionality of the iPhone permits for all of the required pre-requisites for the mobile device and would be a valid option for the study, however one particular problem rendered it unsuitable for this project. The iPhone, much like all hardware manufactured by Apple, utilises its own operating system called iOS, an operating system that is built to run on ARM processors. Consequently, due to Apple's architecture, creating an application for an iOS device requires the application to be compiled from an apple device, such as an Apple Mac or a Macbook. This logistical requirement consequently removed the iPhone as a viable device for the project as access to a Mac device was not available during development and as such, the iPhone would not be able to be used. In future projects, iPhones remain a logistically feasible option, however access to the pre-requisite hardware would be a requirement. Consequently, due to the restrictions imposed when working with Apple products, the mobile device would need to run an operating system compatible with a Windows desktop development environment.

Android devices fit these criteria, as Android can be deployed to from a Windows desktop and does not have any logistical concerns regarding hardware for development. Furthermore, both the Unreal Engine and Unity Engine come equipped with a compiler for Android without any third-party dependencies, thus enabling development of AR applications for Android devices with mitigated logistical concerns. Unity 2019 requires a minimum Android version of 7.0 or later (Google, 2024) for AR to function, whilst the Unreal Engine requires a minimum version of 7.1.1 (Epic Games, n.d.)

Considering that Android 7.0 was released in August of 2016 (Google, 2016), any Android device released after this date would be capable of running the required version of the Operating System. Older devices may be capable of upgrading to Android 7 but these would need to be reviewed on a case-by-case basis.

With this consideration, one of the devices explored was the Motorola G4, an Android smartphone released in May of 2016 with the capability of upgrading to Android 7. With a screen size of 5.5 inches, it fell under the desired minimum screen size but fulfilled the other criteria for deploying an AR application. This device was examined due to rampant availability; the University already owned multiple of these devices and so there would be no requirement to purchase additional hardware. These devices were investigated, with the operating system being upgraded and some sample AR apps being installed, however the performance across all was generally poor, with low framerates, delays in inputs and AR object tracking becoming too inconsistent for it to be effective without causing frustration. Coupled with the screen already being smaller than desired, the Motorola G4 was ultimately removed from consideration. Due to the performance issues of the Motorola G4, a newer device was considered with a higher range of technical specifications to try to ensure that performance would be more consistent and capable of smoothly rendering the range of 3D artefacts without causing issues for the user.

Because performance and consistency were problematic on the previous hardware, a newer device of higher specification was identified as a potential candidate; the Samsung Galaxy S10. Featuring an octa-core Mongoose M4 processor and a dedicated MaliG76 graphical processing unit, along with a 12 megapixel rear camera. These hardware components would allow for higher fidelity graphical rendering with better performance when rendering AR content, along with a higher quality camera that would allow for more consistent spatial tracking of the users environment when positioning and maintaining the location of virtual assets. With a screen size of 6.1 inches, the S10 also fits the pre-requisite for ideal screen size. When tested with the sample AR applications, the S10 performed extremely well, with no obvious performance issues and consistent tracking of assets. With no obvious downsides to the hardware or its performance, the S10 was successfully identified as a viable candidate for the experiment, however there was a singular logistical concern with using it; there was only one device available opposed to the plethora of Motorola G4s, meaning that all testing with it would have to be performed individually rather than allowing a group to simultaneously test. Despite this, it was evident that the S10 was the best performing device of the mobile devices explored and as such, was selected for the project.

After this selection process was completed, the final two devices were identified for the project; a Microsoft HoloLens (1st Generation) HMD and a Samsung Galaxy S10 (Samsung, n.d.) smartphone. These devices offered the development tools required for the creation of both AR applications along with the hardware required to run them with appropriate device performance that would not actively cause hinderance to the users. Both of these operated within fiscal logistics, with the University already owning both devices and thus not adding a financial burden into the acquisition process for the projects. With these decisions made, planning moved on toward the testing of both devices in their target environments.

3.2.4 Testing Considerations

Testing these setups would require multiple testing groups along with a control group to qualify the results obtained and provide a suitable benchmark for comparison. To fully answer the research questions and provide consistency, four testing groups were planned and are detailed as follows:

1. Test One: Control. Participants would be educated on the artefacts without any AR technology used in a traditional classroom learning experience.
2. Test Two: Head-Mounted. Participants would use the Head-Mounted AR application deployed at the Museum and learn about the artefacts from the learning experience.
3. Test Three: Head Mounted. Participants would use the Head-Mounted AR application, but this time deployed at the University in a classroom.
4. Test four: Mobile. Participants would use the Mobile application in a University classroom environment.

By utilising several groups, we can establish statistics for how well each group performed and compare the results to examine the variables from each study to identify trends. Each group consists of fifteen participants each (as was negotiated with the Museum due to their requirements and the logistics of facilitating research). These groups can be further examined in table 1:

Table 1: Testing Group Structure

Group	Testing Location	Technology Used	Testing Variables	Desired Outcomes
Control	Classroom	Projector/ PowerPoint	Pedagogical Methodology	Establish a baseline for memory retention
Focus One (Head Mounted)	Museum	Microsoft HoloLens + Leap Motion. Unity AR application	Head Mounted Device with natural interactions + Museum Environment	Determine memory retention with an AR HMD at a Museum exhibit.
Focus Two (Head Mounted)	Classroom	Microsoft HoloLens + Leap Motion. Unity AR application	Head Mounted Device with natural interactions + Classroom Environment	Determine memory retention with an AR HMD in a classroom environment.
Focus Three (Mobile)	Classroom	Mobile Device + Unity Mobile AR Application	AR Deployment Method / Learner location	Determine memory retention with a

				mobile AR application in a classroom environment.

Table 2: Testing Group Structures

Participant groups were all tested using their specified mediums on an individual basis for focus groups, and collectively for the control group. Immediately after each test, participants were provided with a multiple-choice questionnaire containing questions regarding the artefacts and were instructed to answer as many as they could, being given the choice not to answer any question they did not remember the answer to. Furthermore, participants were tested again after a three-month period to test how much of the information they retained, expanding upon the research by Billinghurst and Duenser (2012a) by an additional eight week margin and thus testing participants over a longer project duration. Participants were contacted by email and sent the second questionnaire digitally, with the same questions being asked. Participants were asked to provide their email address on both questionnaires to be used to compare the data and determine the retention rates, along with their age on the first questionnaire to identify if participant age was a factor in retention.

Questionnaires were deployed using Microsoft Forms (Microsoft, n.d.) with data stored securely within The University of Staffordshire's cloud as part of the data collection included email addresses, and therefore needed to be stored in compliance with GDPR regulations. Microsoft Forms also provided functionality to ensure that certain questions had to be answered, along with the option of scrambling the order of specified questions for the follow-up survey. There is also some visualisation of data in the form of graphs and word clouds, however these were not used as they only showed visualisations of individual surveys without the option of sampling results from multiple questionnaires. Details of this questionnaire are provided in Chapter 4.

3.2.5 Augmented Window Design

As aforementioned, the original design of the application was centred around a narrative experience to tell the story of the fictional character Leo by expanding upon one of the rooms in the exhibit of "The Journey". The room in question was designed to represent a tailors shop in Berlin after having been sabotaged during Kristallnacht, with the walls vandalised and shop fixtures damaged, stolen or displaced from their original locations. Despite this, the surrounding walls of the exhibit contain no windows and no displays; these are solid plaster walls without any materials depicting the outer streets of Berlin.

The notion of utilising this space as a blank canvas for AR was planned, with the idea of an Augmented Window being projected over this space to create a visualisation of 1938 Berlin, both to provide additional visual theming for the AR version of the exhibit, along with contributing toward user immersion in the narrative experience.

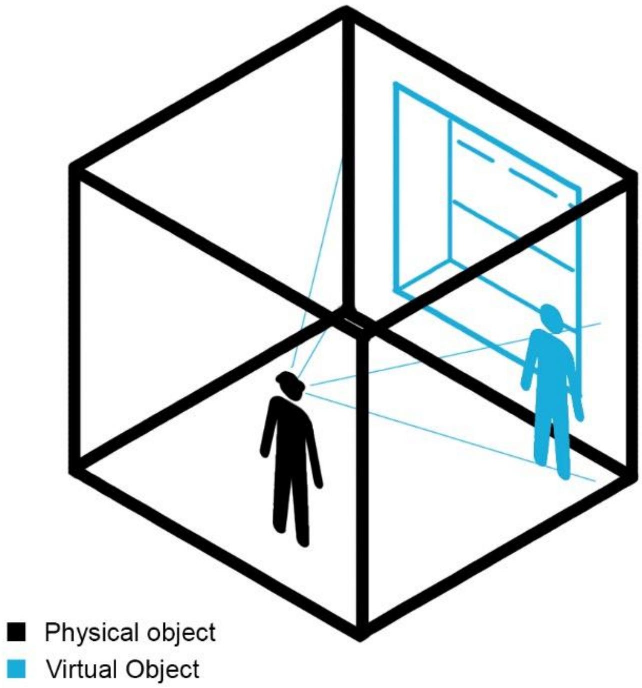


Figure 6: Augmented Reality Window Concept Design

This notion, although simple in premise, has not yet been explored by prior AR study. The concept of the "window" is often used as a metaphor for AR rendering devices and not in a literal sense, which leaves open the possibility of exploring the technical implementation of such a concept along with the challenges that come with it. Despite extensive exploration through existing literature, only one example comes close; an experimental AR application (presented without an official name) developed for Japanese trains (Rosales, 2012) that would project AR content onto a physical train window to create the illusion of objects, such as a hot air balloon, in the surrounding landscape for passengers to play with as a form of in-travel entertainment. Whilst this is a valid exploration of recreational AR, it does not fit the theme of a virtual window to create a new false exterior (or alternatively an interior, context demanding).

A prototype for this build was configured inside Unity using a hollowed out cube as an experimental base, with an image of a Nazi Germany era street projected onto the inside to create the scenery. The vertex normal of the cube were unified to prevent any shading errors from smoothing that could break the illusion and this was functional with a caveat; the sides of the cube geometry were visible at all times, including when the user was standing at the sides of the window (where they should theoretically not be able to see the geometry), this was a by-product of the way AR renders inside Unity and with no way to prevent it from rendering based on viewer angle. This would ruin the illusion if the user deviated away from the designated area in which the window should be viewable and so instead, a somewhat unconventional method was used.

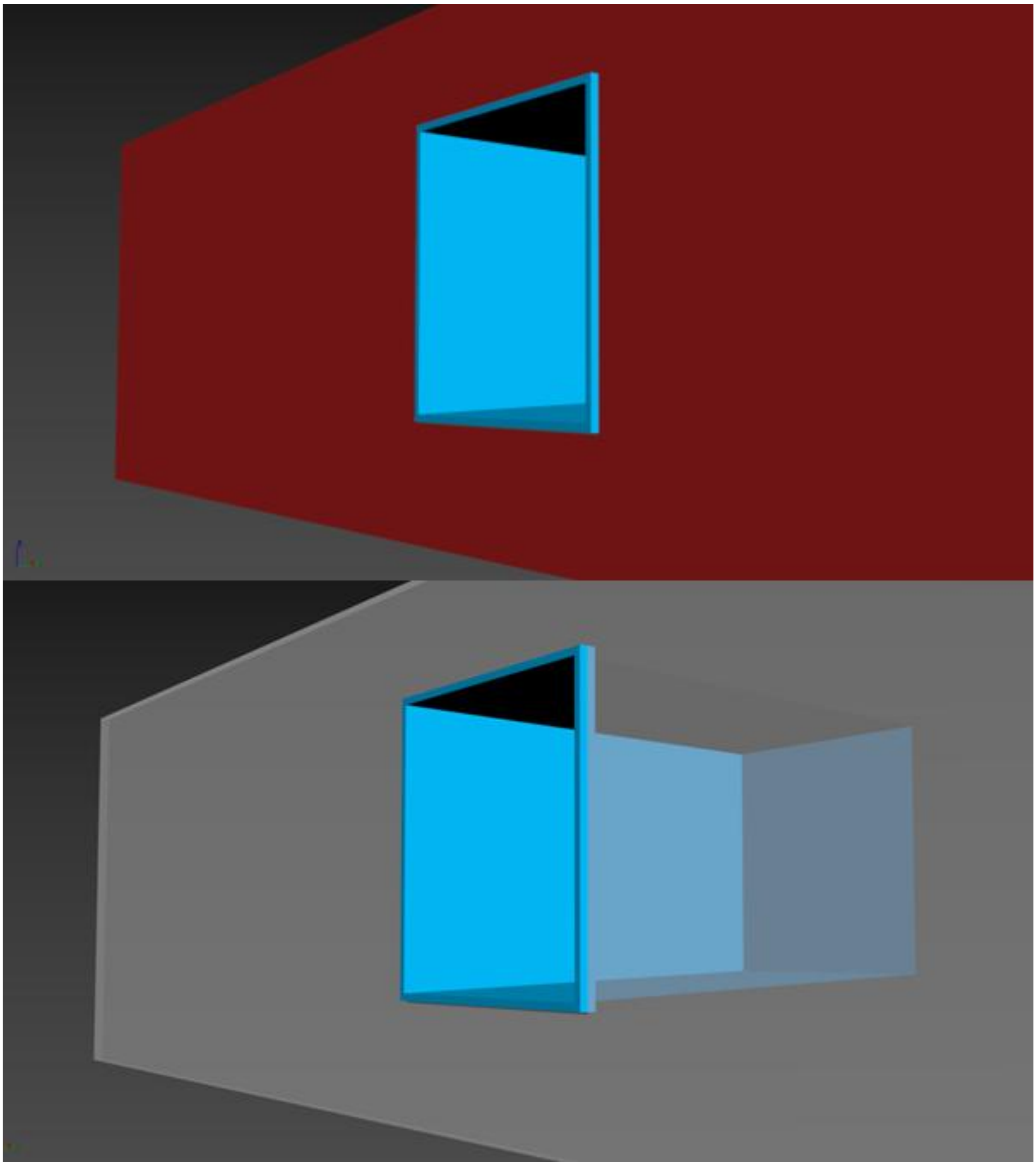


Figure 7: Visualisation of expected window rendering (above) versus visualisation of actual window rendering (below)

The Unity engine features a tool called Render Texture (Unity, 2018), a tool that allows the view of a camera to be captured and used as an albedo texture inside a material, which was then subsequently used to aid with the illusion. By placing the hollowed out box geometry far above the user along with a camera inside it, the geometric depth and scene projection could be captured and displayed upon a flat piece of window geometry which would not be subject to the parallax rendering issue and allow the user to move around the scene without accidentally breaking the illusion of the fake outside environment. As this geometry was far above the user and directly above them, they would only be able to see it if they were to look directly up in the air; a scenario that would theoretically never be a necessity during an AR learning experience. A script was created to synchronise the movements of the rendering camera to the user camera, resulting in a convincing illusion that the user was looking out of a window and adding additional depth to the scene. The shape of the box proved to be something of a limiting factor as it did not accurately convey the perspective distortion expected when looking out of a window, and instead two variations of the cube were made to imitate this; one with a shrinking perspective and one with an expanding perspective. Of the two, the expanding perspective maintained closer adherence to reality and so this was the geometry used.

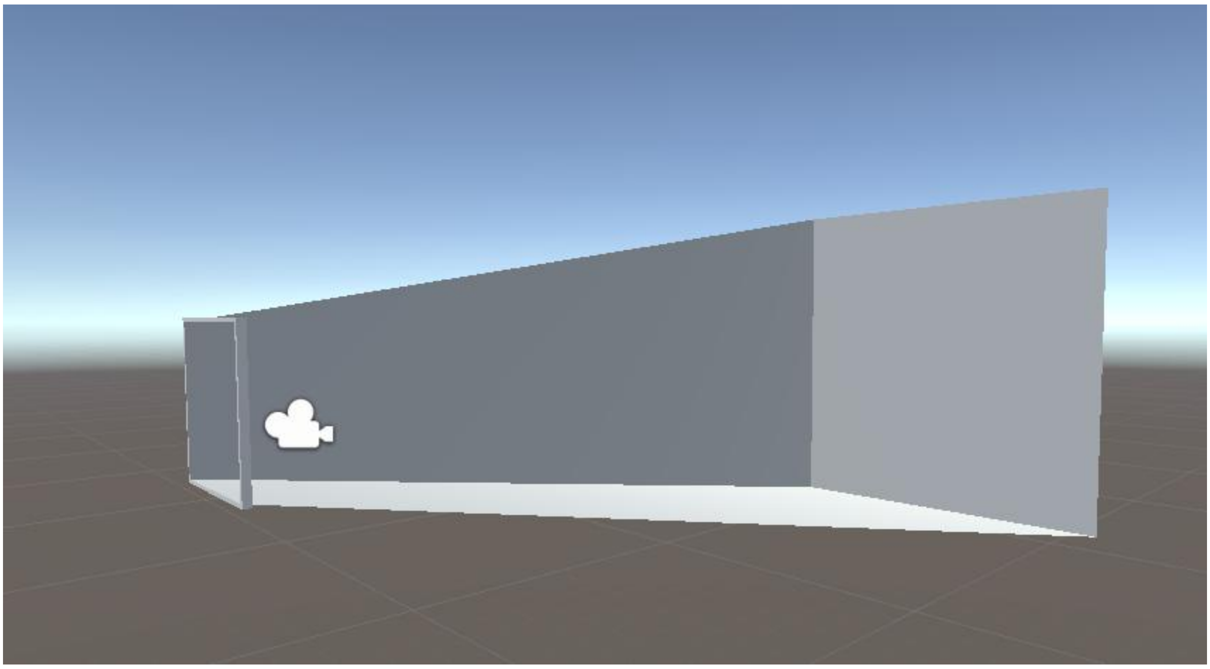


Figure 8: Expanded Perspective Geometry with internal camera

After the direction of the project shifted away from a story experience, the window was no longer required as a narrative component, however it was kept within the project as additional visual decoration and to add some novelty for users at the Museum. Although the topic of immersive illusions is not a research topic of this study, due to the limited amount of literature on the subject, it could prove to be a topic for additional future research into implementation methods of AR to create bespoke and immersive user experiences. This structure for the illusion may serve as future basis for additional exploration into immersive visual illusions for AR or MR projects.

3.3. Classroom Lesson Design

The classroom lesson was written to be structured as a traditional 30-minute classroom learning exercised presented in PowerPoint format. Structured in a classical fashion, the classroom learning exercise was designed to be presented with a single educator addressing the classroom and delivering the educational content through the use of vocals and informative slides relating to the topic. The lecture slides contained information about individual survivors of the Kindertransport with a focus on the belongings brought with them during their journey to the United Kingdom. Included in the slides were photographs of the survivors and their families, imagery depicting their homes prior to the war (where applicable), videos of their testimonies of their experiences and recollections of the era, along with imagery depicting the belongings they brought with them in the Kindertransport.

Figure 9: Screenshot of the Classroom Lecture Slides

As the classroom experiment was structured to replicate a traditional classroom teaching experience with an educator stood at the front of the room, speaking to the learners directly with a PowerPoint presentation being used to provide structural and visual referencing. Participants were permitted to ask questions if they wished to learn more about the content as they would with any other classroom. The room selected for delivery was a University classroom fitted with desks, chairs, a lectern with a microphone and surrounding speakers. The lectern was equipped with a desktop PC running Windows 10 and connected to a projector.

Demo props were considered for usage during the talk to provide additional learning stimulus and context for the learners, however there was limited availability for this as many of the artefacts were bespoke or have no suitable modern equivalent that could be used as a proxy. However, one of the artefacts from the learning content was a Knaurs Konversations Lexikon (Knaur, 1932) (An encyclopaedia) that was printed in the 1930s and was donated to the museum. As this artefact contains a personalised ex-libris, it is preserved in the museum along with the other artefacts and as such are not suitable for handling by the public. However, as the Lexikon was a widely printed book, a copy that was purchased early in production to serve as reference. Because of this, it was also used in the classroom experiment by being passed around to participants who were encouraged to peruse it in the same manner that other supplementing resources would be used. Unfortunately, the other artefacts were far too personal and consequently were not suitable to be emulated with similar props or alternative proxies. For example, the dolls brought over by several of the victims were hand-made, often by local artisans, and consequently any similar toys are remarkably difficult to locate as many have been lost, destroyed or are considered to be collectors' items. The suitcases and hat boxes from the experience are less rare and can be located through antique and vintage markets, however these are large, bulky and generally not suitable to be passed around a classroom. Furthermore, the necessity of props for the remaining items is debatable; the learners (as adults) would reasonably expected to understand the role and purpose of coat hangers, woodworking tools or napkins, and as such these were not required. The Writ of Passage, whilst an interesting document, is not something that could be obtained whether in full or with a suitable proxy as these were all bespoke and are generally difficult to obtain, attempts to create a replica would be low quality and have questionable learning benefit. The lexicon, as an encyclopaedia, is a historical item made redundant by the digital era and as such would be of interest to learners, particularly the drawings and diagrams inside which may be of visual interest.

It was observed that learners did not ask any questions on the details of the Kindertransport, but did ask questions pertaining to the artefacts, such as their background or historical context. For example, one participant requested additional information on the uses of hat boxes, as these were a common item in the 1930s and hats would be appropriately stored between uses, however in the 2020s, hats are seldom worn as a formal accessory and are not afforded any extravagance for storage. Another learner requested further information regarding if the Kindertransport had influenced future refugee policy in the United Kingdom, specifically regarding refugees from the war in Ukraine. Although this topic was not part of the research, it demonstrates that learners were contextualising the learning content to draw parallels between the past and the present, something which is often considered an objective of studying history.

Within the context of a classroom learning experience, learners are typically permitted to ask questions to further expand upon their knowledge and understanding providing the educator knows the answers, something which is not always a guarantee but the educator also has the option of directing learners toward relevant learning resources if necessary. This also carries the benefit of communicating to the educator that the learner is engaged with their learning and actively pursuing the subject matter, something which is not available in AR or VR learning experiences as the applications can only provide the information programmed into them by the creators.

3.4. Head-Mounted Application Development

3.4.1 Head-Mounted Hardware Design

Both the Head Mounted and the mobile applications were required to host identical learning content to assess which method was most appropriate for long-term memory retention. However, each device has different methods of Human-Computer Interaction which would subsequently alter how each group would engage with the learning content. Assuming standardised design conventions were employed for the Mobile Application, participants from the Mobile group would be able to seamlessly interact with the application as it can be reasonably assumed that participants are familiar with smartphone operation due to their streamlined integration with modern society, considering that 87% of adults in the UK own a smartphone device (Boyle & Barber, 2022). By comparison, participants from the HMD groups would be at a comparable disadvantage as the HoloLens is not a societally integrated technology and so users cannot reasonably be expected to understand how to operate it without providing them with training, particularly when considering that only an estimated six percent of adults in the UK own a HMD for VR (Laricchia, 2023) (statistics for AR HMDs are not available but it can be assumed to be lower due to the lack of commercial entertainment media created for AR devices). This issue is further compounded by the innate limitations of the HoloLens device; the device only has two primary methods of interaction: the air tap gesture (Microsoft, 2021b) and voice commands.

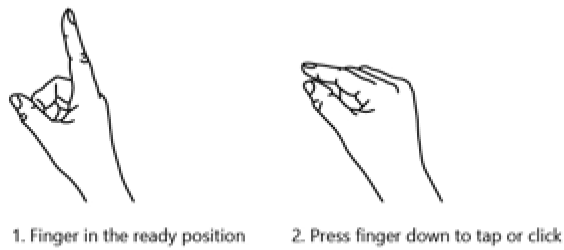


Figure 10: Air Tap hand gesture diagram (Microsoft, 2021b)

The Air Tap gesture is akin to performing a Left-Click function with a standard computer mouse, which allows for basic interaction but nothing more advanced or complex. Furthermore, the gesture must be performed at an appropriate speed, with the users hand in a location visible to the sensors of the HoloLens which can be confusing for new users as they must practice the gesture repeatedly to develop an understanding of how to consistently perform the gesture. This is an unfortunate oversight in the usage of the Hololens; upon using the device for the first time, the first user will be prompted with a tutorial for how to fully control the device, however this is rather extensive and takes over thirty minutes to fully cover all of the controls. Although the tutorial can be accessed at any time from the main menu of the device, it must be taken in full; it is not possible to load only the Air Tap segment for users to practice it prior to using an application. This adds a logistical requirement that users must be taught the gesture prior to using the application with minimal opportunity to practice it, leaving margins for error and subsequent frustration for them if they are unable to correctly perform the gesture when the application is running. To mitigate this, options were investigated for configuring a third-party peripheral to integrate with the HoloLens and allow for alternative interaction methods to provide a more engaging user experience and mitigate the complexities of learning the operational methods of the device.

Peripherals such as the Xbox One Controller (Microsoft, n.d.) were contemplated as they would permit the user to engage with content through a standardised interaction medium. Given that game consoles are also a societally integrated technology, even should a user not be familiar with the Xbox (Microsoft, n.d.) it would be reasonable to assume that they had some prior experience of using a console controller. Despite this, implementing controller would require establishing input mapping and controls for each interactive component, which then have to be meaningfully communicated to the user and subsequently learned to effectively interact with the system, which provides both a barrier for entry and a potential distraction from engagement if a user experiences difficulties. Instead, gesture-based control peripherals were prioritised to reduce the barrier for entry and allow new HoloLens users to interact with the system using natural interactions rather than mechanical ones. Furthermore, the use of a game controller implies connotations that the experience will be gamified or include elements of gameplay, which is not the intended outcomes of this learning experience. Users who have exclusively used game controllers for gameplay experiences may mentally position themselves to experience gameplay when picking up a controller, and so it could be irresponsible to use a controller as it may put users into the incorrect mental state for the learning experience.

The Microsoft Kinect for PC (Microsoft, 2022b) was considered as a potential option as it would provide the option for gesture-based inputs ranging from hand gestures to motions with the user's entire body. Unfortunately, it proved to be unsuitable for usage as the Kinect would introduce logistical issues; the device was too large and too heavy to be worn on the user which would limit the device to being placed at a stationary point in the room; therefore requiring the user to perform all gestures at a designated position and rotation where they could be seen by the sensor. As one of the intended roles of the application was to augment a museum exhibit, requiring the user to remain at or constantly move back to a designated location was far too limiting.

Alternative gesture-based controllers were also considered, such as the Gest (Gest, 2016) controller. The Gest controller is a wearable peripheral that allows users to interact with PC and mobile devices by performing hand gestures. The device was launched on Kickstarter in 2015 but has not been available for purchase since, meaning that it was not possible to acquire one for this project. The Essential Reality P5 Glove (Jasandre Pty. Ltd, 2006) was also considered as an option but was similarly unavailable for purchase due to the age of the device along with uncertainties regarding whether such an old piece of hardware would even be compatible with modern systems. Newer glove-type input methods were also investigated including the SenseGlove Nova (SenseGlove, 2021) and the Prime X Haptic VR Glove (Manus, 2022), however these devices are primarily intended to provide haptic feedback in VR experiences and as such are expensive purchases at €4499 and €3999, putting both out of budget for the project. Although they would have provided the required interaction functionality, the project would require a device capable of gesture-based inputs without the haptic features and other expensive design features that would not be utilised by the application.

Logistically, any proposed peripheral would need to attachable to the wearer, light enough to not be cumbersome and still permit the user to naturally perform a series of varying gestures that could be interpreted as controls, whilst also being within the confines of the budget for the project. A solution was found with the Leap Motion (Ultraleap, 2012) gesture detection sensor. The Leap Motion sensor allows for a full range of gesture-based interactions to be interpreted by an application and processed into inputs, theoretically permitting a user to naturally engage with Augmented content by performing simple movements, such as reaching out and picking something up with a grabbing motion, etc. Using the Leap Motion with the HoloLens is not a new concept; the notion has been done before by HoloLabs (2022) who built and released an open sourced 3d printable mount to attach the device to the headset. Previous attempts at integrating the two devices have been limited however (Kyriakou & Hermon, 2019), as the Leap Motion must remain connected to a computer to function as intended, therefore limiting the potential range of the user or requiring a cable tethering them to their computer at all times.

Resolving this logistical challenge required an adaptation to the approach of deploying the HoloLens to a user. As the HoloLens does not have a standard USB connection port, there is no means of manually connecting the Leap Motion to it and even if it could, it is uncertain if the drivers for it would be compatible with the Windows Holographic Operating System. As the two devices would not otherwise be compatible, a solution was found in the form of using an intermediary device between the two. The device would have to be small and light enough to attach to a user in some capacity whilst being fully powered by a battery rather than an outlet. A Raspberri Pi (Raspberry Pi Foundation, 2012) was considered but unfortunately was not applicable as the Raspberry Pi utilises an ARM processor and the Leap Motion drivers require an x86 architecture processor to execute, thus rendering it incompatible as it cannot run the required software. A Rock Pi X (Radxa, 2020) would have been appropriate as this variant utilises an x86 processor, however this variant was not release until after a solution had been found. Arduino (Arduino, 2023) boards similarly did not use an x86 processor and thus were also not appropriate for the project.

Factoring out alternative single-board computers, a solution was instead located by searching for smaller devices that used both an x86 type processor exclusively to mitigate the CPU architecture issue, along with natively running an operating system compatible with the Leap Motion drivers. After exploring for possible options, a device was located called the ACEPC AK2 Micro PC (ACEPC, n.d.), a small device that runs Windows 10 natively and has an x86 processor. This would allow the Leap Motion drivers to natively run on it without any further modification being required. The AK2 also has a built in Wi-Fi radio which would allow a means by which it could communicate with the HoloLens. After conducting performance tests, the device was found to be an appropriate option as its 1.5ghz Intel Celeron processor and 4 gigabytes of Ram were powerful enough to run the drivers and Leap Motion software without any lapses in performance. Additional exploration was performed for other suitable devices, however other devices with similar architecture were significantly more expensive as they were marketed as dedicated devices for running computer game emulation with higher fidelity graphical rendering capabilities than the AK2. This would be beneficial if that were required, however the device was only needed to run and parse the drivers and as such, the other devices were decided against.

Despite locating a potential device, there was still a logistical challenge for how the two devices would communicate to facilitate the transfer of inputs from the Leap Motion to the HoloLens. Software packages for such a purpose were investigated, however a solution was found within the construction of the application itself rather than relying on an external tool to facilitate input transfer. The application was built using Unity (Unity, n.d.) version 2018.4.7f1 to utilise the Mixed Reality Toolkit (Microsoft, 2022c) (furthermore abbreviated to MRTK) as recommended by the Microsoft Documentation (Microsoft, 2019) in the official supporting content for developing applications for the HoloLens. As a game engine was being used to facilitate the application, development shifted toward investigating the networking capabilities of the engine with the intention of utilising Unity's UNet (Unity, 2023) framework for multiplayer and networking. UNet was a deprecated solution, with no further official support provided for it as Unity was developing a successor framework (Since released as MLAPI,) which was in development at the time of the project) and so consequently, a third party Network framework was instead chosen called Mirror

(Mirror Networking, n.d.) a framework designed to imitate the functions of UNet but with ongoing support available.

Mirror is a free netcoding system developed by the Mirror Networking team and is open source to allow users to contribute to and develop branches of its codebase. The design functionality of Mirror utilises peer-to-peer networking (henceforth abbreviated to p2p) that allows a computer to be designated as the "host" server, which other computers can then connect to. Within the context of online gaming, this is generally considered to be a poor solution as any latency issues suffered by the host will likewise cause poor network performance for all users connected. However, in the scope of this project, this was not a concern as both devices would be connected via the same local network and so would not be subject to latency caused by the internet.

Alternatively, the other solution available at the time of development was the Photon plugin (Photon, 2024). Photon (Now known as PUN) is a closed-source plugin that offers a free version with limited functionality, or a premium version that costs $95, something which would add to the development costs of the project. Upon further examination, Photon and Mirror both offered identical functionality, however Photon had one significant difference: it does not use a p2p model for networking and instead relies on a dedicated server to run. Utilising this framework would also require a dedicated server as part of the design of the project to facilitate this and so after consideration, it became apparent that Mirror offered the same functionality with fewer disadvantages. Consequently, Mirror was chosen as the netcode for the project.

The concept for this design was as follows; the user would perform a hand gesture to interact with an object, which would be received by the Leap Motion and relayed to the Unity application running on the AK2. Unity would then trigger the interactive component, and Mirror would replicate that interaction on the application running on the HoloLens. To the user, it would appear as though all interactions and processing had occurred through the HoloLens without interruption or delay.

This was not without complication however as networking solutions are an advanced programming concept with extensive considerations that need to be made. Network ports need to be opened to allow a client to connect to the server. Each object inside the scene needs authority assigned to it to determine if it is controlled by the server or to the client connected to it. Any variables whose values must remain consistent across the network must instead be re-designated as a Syncvar (or a Synchronised Variable). Networked code requires the use of Hooks and Callbacks to trigger appropriate behaviour when synchronised values change, or when network events are executed. This completely changes the foundations of a project, as it is no longer sufficient to design or build any content that runs natively in Unity; instead it must have any network logistics planned ahead of time. Due to this, all prior interactions and designs (many had already been prototyped during familiarisation with Unity and the C# programming language) had to be retroactively adjusted to allow for networking to function.

To deploy this solution with full mobility and without tethering the user to a physical location, the AK2 was attached to the user via a backpack and powered with a RAVPower PD 3.0 battery bank (Ravpower, 2020) as the AK2 power cable required a 230 volt AC socket to connect to and the PD 3.0 was the only consumer-grade battery bank to contain one that was available for sale at the time of development. The Leap Motion was attached to the HoloLens using the mount created by HoloLabs (Holo Lab inc, 2020) and connected to the AK2 with its standard connection cable, fed down the back of the HoloLens and into the backpack behind the users head where it was not at risk of snagging or causing injury to the user. Although placing the computer and power supply into a backpack is not an ideal solution for temperature regulation, it proved to be functional as a solution and effectively contained the cables to prevent any tripping or snagging hazards. Additionally, this configuration was tested for prolonged periods prior to testing to ensure the equipment would not become too hot as this could be dangerous for either the user or the devices, and fortunately the temperature did not grow to any level that would make the backpack uncomfortable to wear. As a precaution however, the devices would be removed from the backpack and left to ventilate between uses to ensure they did not overheat.

To facilitate the networking aspect, both devices needed to be connected to the same network and so a TP-Link TL-WR841N wireless router (TP-Link, 2021) was utilised to ensure consistency. This permitted for an extra failsafe within the design of the system; both devices could use a static IP address that would allow them to always consistently locate one another by always using the same internal network address. Although there are workarounds for using dynamic IP addresses, any difficulties in getting the applications to connect on the Museum or University networks would be difficult to debug without connecting the devices to a screen (something which both devices are intended to work without) and so to mitigate potential future problems, the wireless router was considered to be a key component of the design. Additionally, although any wireless router would allow the devices to communicate, there was a risk of varying network speeds causing inconsistent user experience between locations due to either the technical specifications of the routers at each location or by the amount of traffic generated by the number of users on each network at any given moment. Using a private router removed this concern as the only traffic on its wireless network would be the HoloLens and the AK2.

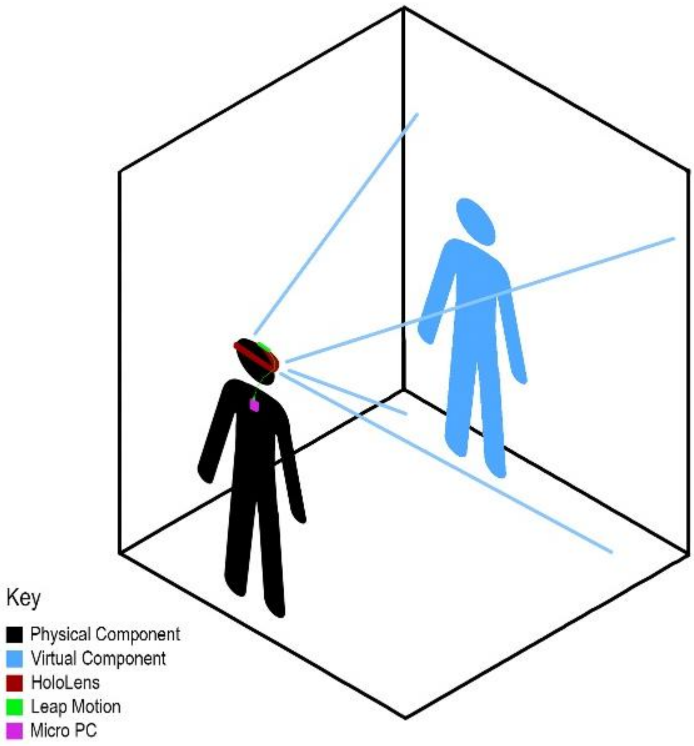


Figure 11: HoloLens Configuration Diagram

Figure 12: HoloLens Configuration Photograph (With Permission from Robert Ellis)

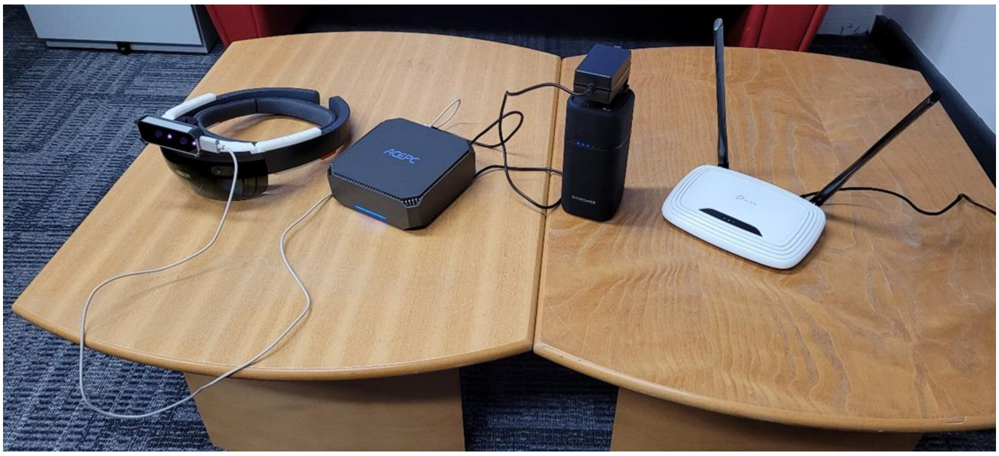


Figure 13: HoloLens Configuration (Unworn)

Even though the design now planned for a static IP address, there was still a key flaw in this configuration that needed to be addressed; the IP input. The design of Mirror prompts a user to make a decision when they run the Unity project: either create a server and join it as a client, enter an IP address for a server and join it as a client, or run as a server only.

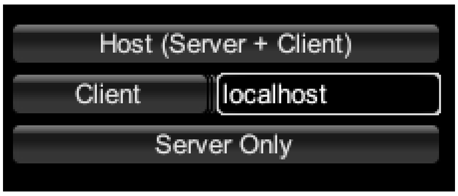


Figure 14: Mirror Networking User Interface

On a PC, mobile device or games console, this would not be a problem as the user could make a selection by interacting with the button, and typing in the IP Address they wish to connect to with their keyboard. However, the server was intended to run without being connected to a monitor or external peripherals, and this user interface required someone to click the "server only" button every single time the project loaded. Furthermore, the HoloLens would also need to type in the IP address for the server each time the project was loaded, which would require use of the HoloLens keyboard and subsequently, the air-trap gesture. This produced a logistical challenge; either the system has to be set up before being handed over to a user, or the user has to learn the air-tap gesture to type in the IP address, which negates the purpose of designing the system for gesture based inputs. Instead, a different solution was identified that involved modifying the design of the Network Manager component inside of Mirror. The Network Manager is a component that handles all connections inside Mirror and loads the User Interface responsible for loading as a client or server (pictured in Figure 14). Upon loading, the code for the Network Manager would show the User Interface and execute functions based on the user's selection, however, this could be modified to instead run these functions automatically.

```
void Awake()
{
    manager = GetComponent<NetworkManager>();
    if (Application.platform == RuntimePlatform.WindowsPlayer)
    {
        manager.StartHost();
    }
    else
    {
        manager.networkAddress = "192.168.0.107";
        manager.StartClient();
         //showGUI = false;
    }
}
```

Figure 15: Customised Mirror Network Manager Code

The User Interface command was commented out of the code to prevent it from running and the rest of the code was then wrapped in a simple If statement; if the code detected it was being ran on Windows, it would automatically execute the command to run the project as a Server. If it detected it was being ran on anything else, it would automatically execute the code to run as a client, with the static IP address already being passed as a hard-coded parameter. This meant that the server would always need to be switched on first, but that the HoloLens version of the application would immediately connect without any prompting from the user once ran,

3.4.2 Head-Mounted Application Design

Designing the learning application required a means for users to interact with virtual content at their own pace and learn about the things that interest them. As the theme of this project was to educate users on virtualised versions of artefacts, the interactivity was focused around users being able to select individual artefacts to learn more about them in a meaningful way. Whilst it was possible to draw text upon a wall to provide a written history of each artefact, doing so would be a wasteful use of AR as the same could be achieved without use of the technology. Instead all interactions needed to fully utilise the benefits of AR, including the ability to use multimedia formats.

The application was designed with this interaction methodology as a key consideration for all interactive components. The Leap Motion plugin for Unity once contained a gesture recognition package that would allow for gesture-based inputs to be implemented directly into the engine with a series of presets for developers, however it was removed in a later version of the SDK without any reasons specified. Consequently, a plugin called the Essential Leap-Motion Gesture Detection plugin (The Great Alpaca, 2019) was used to restore this functionality. This plugin permitted triggers to be established that would initialise various functionality when specific gestures were detected by the Leap Motion, such as a fist or a flick of a finger.

The only detriment to these triggers is that if multiple objects or interactions are designed to be used with the same gesture, all of them will occur simultaneously when that gesture is performed. For example, if multiple objects have triggers that occur when the user performs a thumbs up gesture with their right hand, every single one of them will instantly execute as soon as the gesture is detected, which makes for a very chaotic user experience. To mitigate this problem, a gaze system was implemented for interactive components; when the user turns their head to look at an object, it will become the active object which will make it gain a light blue outline. If the user looks at another object, the previous one will lose its highlight and it will instead be applied to the new object. When the user performs a gesture, the interactions will only occur to an object with a visible outline, thus preventing every object from moving simultaneously or some other such undesired outcome. A proximity check was initially going to be used for this purpose, however it caused too much network latency as the server was constantly having to check how close the user was to any given object and the result was detrimental to user experience.

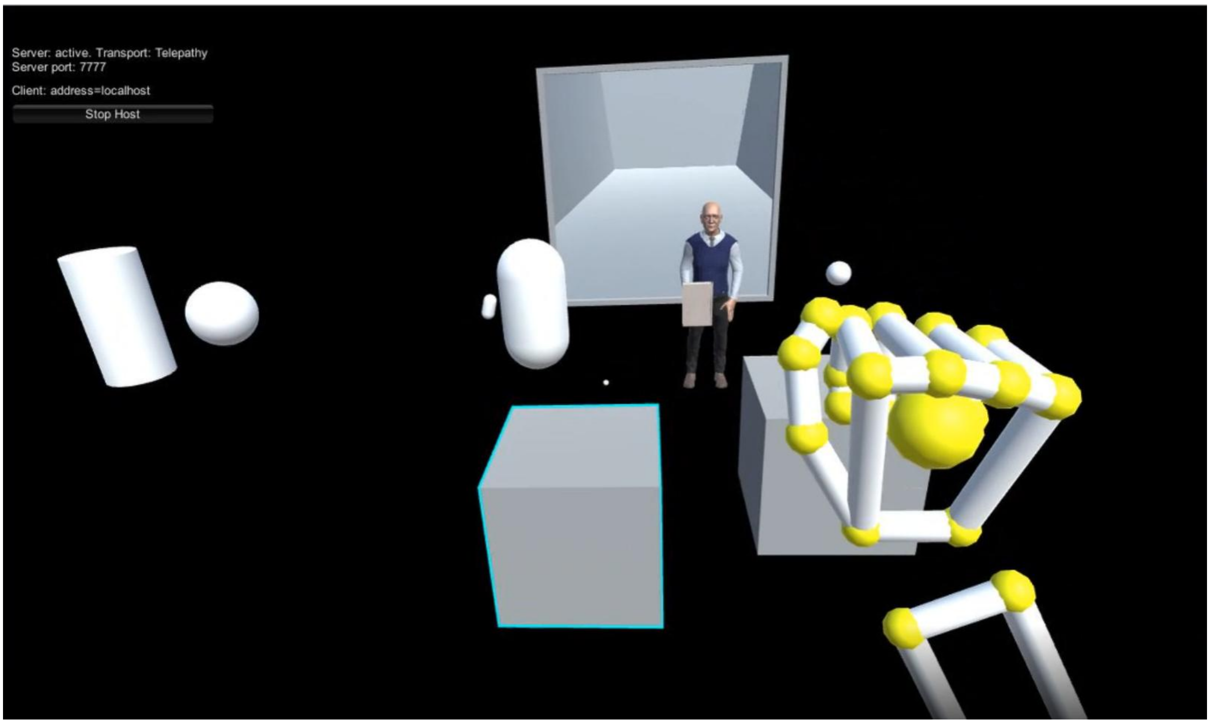


Figure 16: Selective Asset Targeting for Gesture Controls (Debug view)

When performing a gesture, the system would process this in two locations. The server would give authority over the camera (attached to the users head) to the HoloLens. Whenever the user moved or turned their head, the camera in the virtual scene would also move/rotate and communicate the movements back to the server. A ray would constantly cast from the camera to the virtual objects and when the user looked at an object, it would become highlighted in blue to show that it was the active item. This worked by giving every object an Outline component, which was disabled by default, but would be activated when hit by a successful raycast from the camera, along with disabling the outlines of any other objects in the scene. The outline would remain active until another object was looked at, regardless of if the user kept their head facing toward it or not, as interactions would otherwise require the user to continually move their head to keep looking at the target object.

All gestures were designed with the intention of being intuitive and matching real-life expectations of how one would interact with any given object. For example, if the user wanted to pick up an object, the dedicated method for the interaction was to reach out and make a fist to imitate the action of grabbing an object. With a virtual book, an interaction of flicking with ones index finger would trigger an animation to make the book flip its pages as to be perused at the users leisure, and so on. As an unfortunate limitation, all interactions were designed to be performed by the users right hand, as The Essential Leap-Motion Gesture Detection plugin requires all interaction triggers to specify which hand will be used to call the interaction. This would later inconvenience two participants who were left handed, however they were still able to operate the system without issue.

Figure 17: Swiping Gesture Diagram

For the purposes of learning about any artefact, the system was designed for a Virtual Educator to be the primary source of conveying information to the user. Virtual versions of all the Artefacts from the exhibit at the National Holocaust Centre & Museum were created in 3D using Autodesk Maya (Autodesk, n.d.) and placed within the scene, which the user could then pick up and present to a Virtual Educator character who would then provide the user with context regarding that artefact. This included fully recorded voice lines and motion captured, lip-synced animations, along with a projected photograph of the real-life artefact for the benefit of the user. This would permit the user to examine the 3D model variant within their AR environment, as well as gain additional context whenever they so wished. The virtual artefacts were positioned around the AR scene using measurements from the real exhibit so that they would be positioned in real locations, such as on a counter or a shelf. The purpose of this was twofold; first to augment the exhibit and expand upon it with use of the virtual content, and the second was to provide an objective for the user, to search and locate the artefacts.

3.5. Creation of the Virtual Educator

The Virtual Educator character was originally intended to utilise the likeness of one of the Kindertransport survivors by using Photogrammetry and having them record all their voice lines, along with any personal anecdotes they were able to share about the era. Unfortunately, due to the Covid-19 pandemic, this became impossible for health and safety reasons, and so instead an original character was instead using a composite of features from the survivors, such as clothing choices and his apparent age. Using this approach does present a concern with accuracy, as the educator is now an interpretation of history rather than an accurate representation of it (Thompson, 2017), however to compensate he is only presented as an educator and not as a representation of any real-life person. This Virtual Educator character was then dubbed "Gerald" and was provided with a full facial animation rig to allow for lip-synced facial animations. A professional voice actor was hired to record dialog lines for the application as once again due to the pandemic, it was necessary to recruit someone with their own facility to record audio.

Figure 18: Gerald Character Model

The character of Gerald (pictured in Figure 18: Gerald Character Model) was created in several stages. The high poly model was created inside Zbrush 2020 and utilised high-poly sculpting techniques to create the primary and secondary forms of the anatomy. Tertiary forms were added using a TexturingXYZ (n.d.) multi-channel displacement map and brush alphas. The outfit for the character was simulated using Marvelous Designer to attain realistic garment creasing, as per current industry standards for character creation pipelines (CLO Virtual Fashion & CD Projekt Red, 2021). The chosen outfit was inspired by the clothing worn by the Kindertransport in their pre-recorded educational videos.

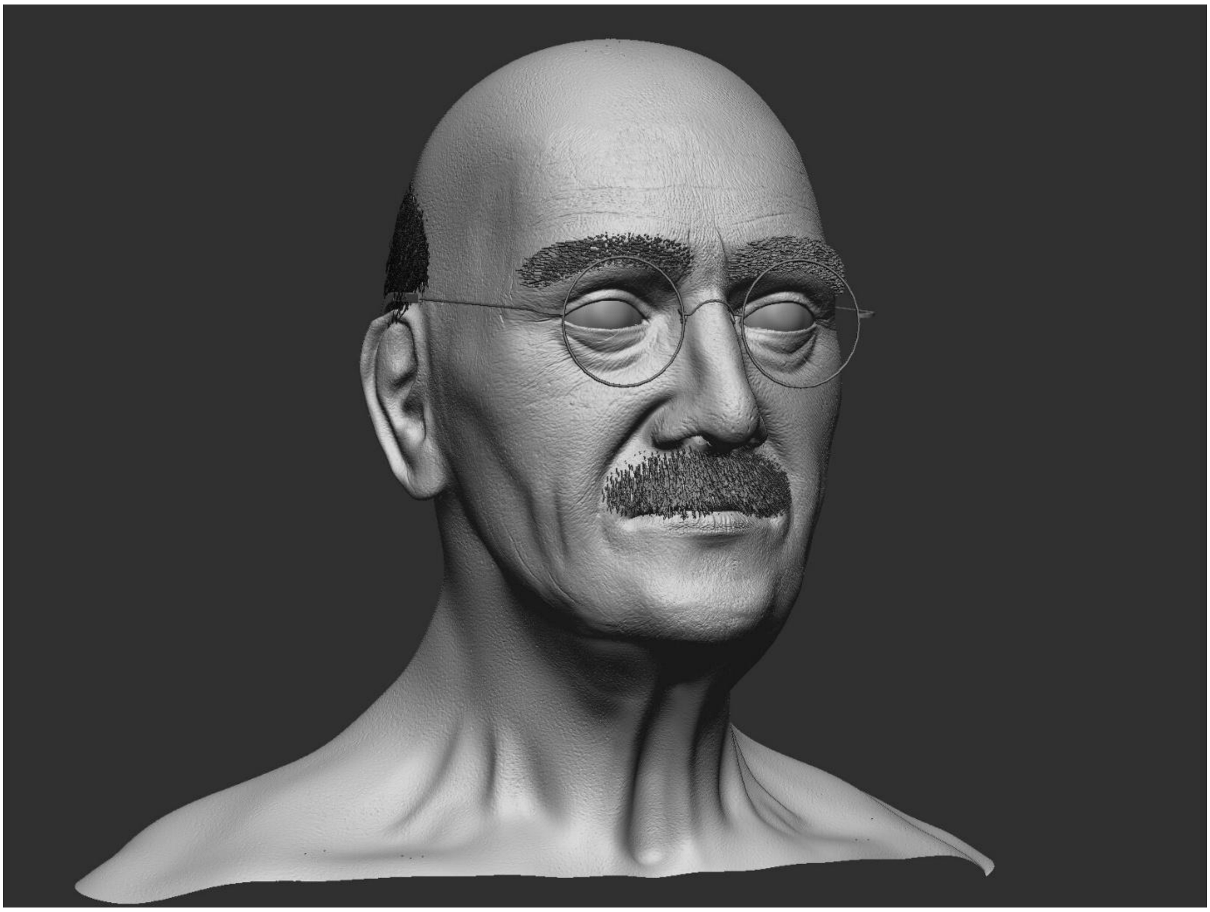


Figure 19: Gerald High-Poly Models

Data from the TexturingXYZ Multi-Channel Albedo was used to project skin texture detailing onto the texture file, along with some procedurally generated surface detailing to further emphasize the age of the character, such as broken capillaries, exaggerated eyebags and liver spots. Pale shadowing was also painted over the pupil of the eyes to replicate the effect of cataracts. Due to the technical limitations of alpha rendering within the HoloLens and mobile builds, a minimalistic approach was taken toward the hair creation toa void performance issues and so Gerald was left mostly bald, with a crown of hair around the back of his head inspired by the character of Captain Picard from Star Trek. Several of the Kindertransport survivors had facial hair, and so Gerald was given a simple moustache to imitate this.

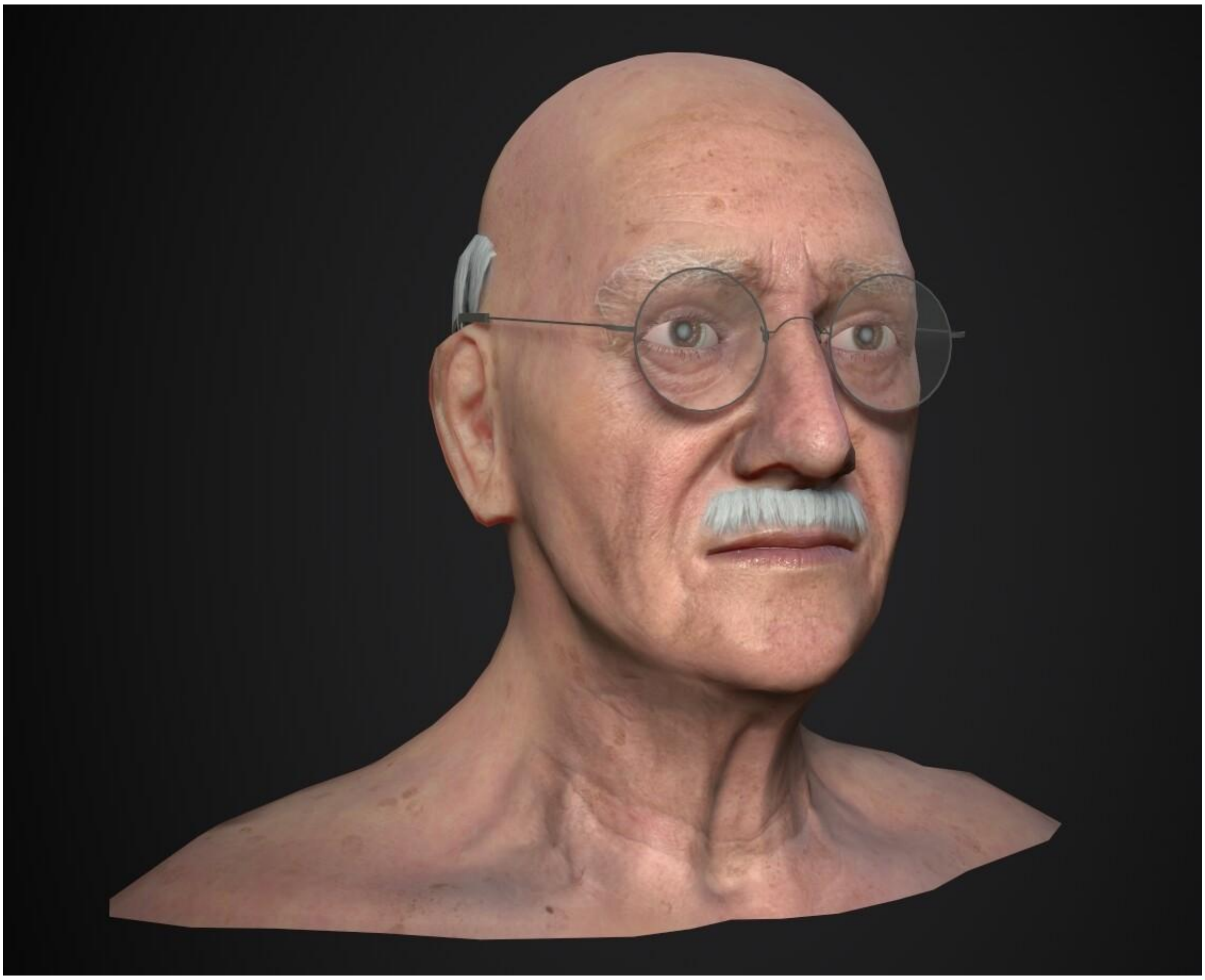


Figure 20: Gerald Skin Texture

Gerald was fully rigged for animation, with animations created using motion capture techniques. The body animations were recorded using the University's Vicon Motion Capture studio to achieve full real-world compliance with motion. The facial motion capture facilities were unavailable at the time of recording due to the Covid-19 pandemic as the process would involve close contact with an uncovered face to prepare for capture, which would have been in violation with post-pandemic health and safety procedures. Instead, FaceRig Studio was used to capture motion, which only required a webcam and could be safely performed alone. This resulted in a full range of facial motion which was then lip-synced to the audio from the voice actor to achieve an accurate set of animations.

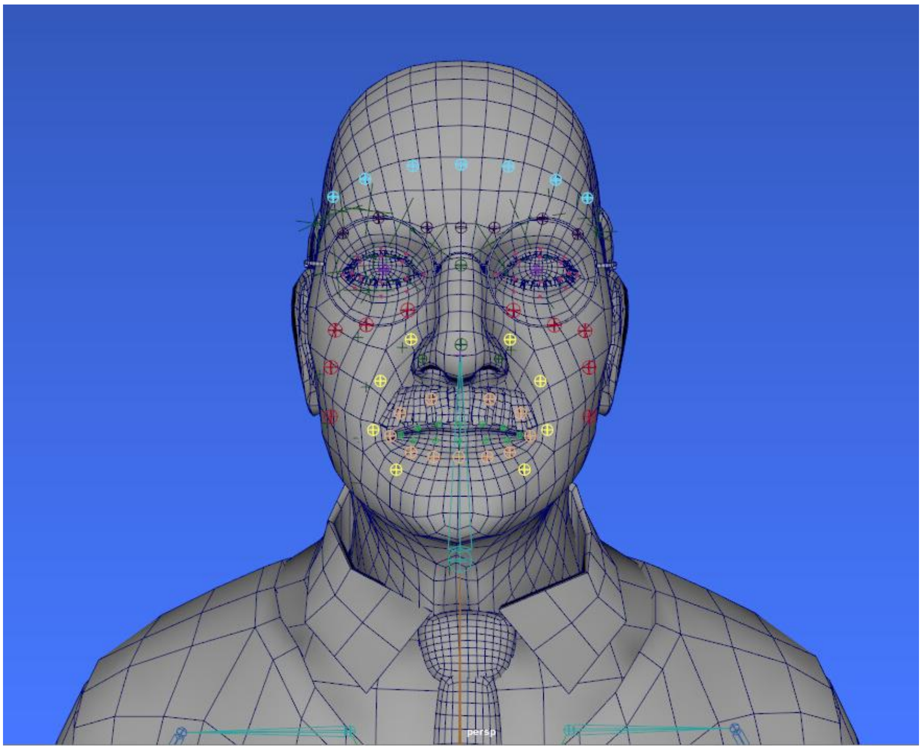


Figure 21: Gerald Animation Skeleton

3.6. Mobile Application Design

Deploying the application to a mobile device required significant adjustment to the design to ensure it would be suitable for usage on a smartphone device. The Leap Motion would not be available for mobile devices and even if it were, it would not be appropriate. Gesture-based controls were only utilised for the Head-Mounted application to compensate for limitations of the HoloLens, however mobile devices include an alternative range of input methods that can be used without needing third-party external peripherals.

Within the interest of testing the AR method over the learning content, the same application design was applied to the Mobile application; the user would still search for virtual artefacts and give them to a virtual educator to learn more about them by being educated in the same manner. The main difference would be how the user interacts with the scene; instead of using their hands, the user uses the touch screen of their device. When the user taps on an object, the object is collected into their inventory menu. Items in the inventory can be pressed like buttons, which will in turn trigger the Educator to begin teaching about that item.

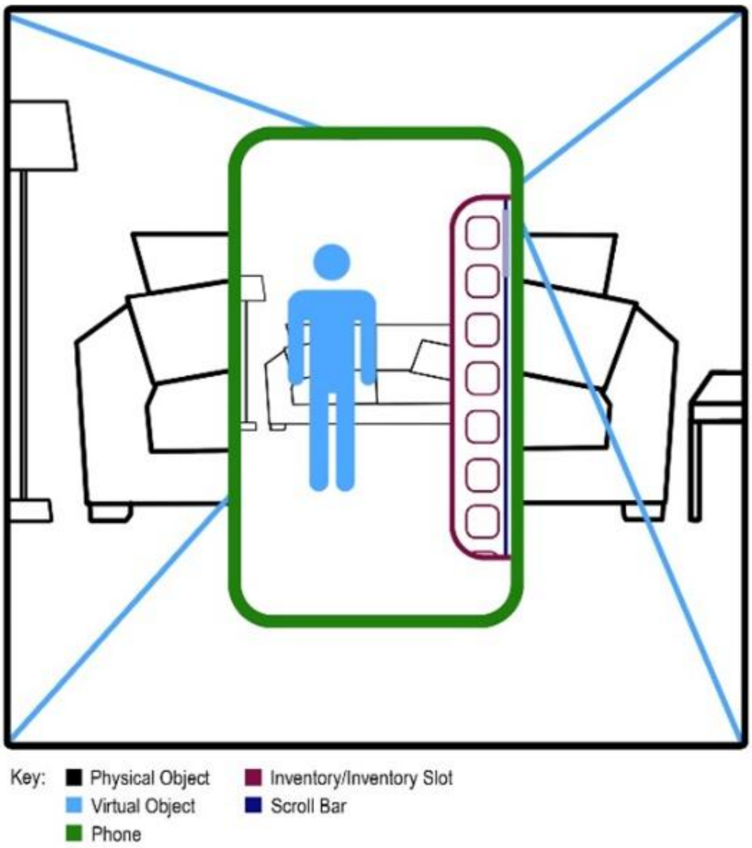


Figure 22: Mobile Configuration Diagram

Unlike the HoloLens application, the virtual artefacts do not have fixed positions within the scene as per an agreement with the Museum when the application was being developed. The Mobile application needed to be a learning resource with the potential of being deployed to various environments, such as different facilities within the Museum as well as the potential of being used in classrooms too. As such, the design was instead altered to allow for logical placement of all virtual assets within a new environment each time the application was ran. Upon launch, the application will begin scanning the users environment to create a spatial map of all surfaces using Unity's AR Foundation Framework (Anon, n.d.). Whilst scanning, the application will perform ray casts from the camera at flat surfaces and store the locations of successful ray casts in a list. After thirty seconds of scanning, the application will then take a series of random locations from the list and attempt to instantiate the artefacts and the virtual educator at those locations. The application will also use the collision boundaries of each object to determine if they are overlapping; if so, it will attempt to move an artefact to a new location without potential overlap to prevent objects being placed over each other. The result of this system is an AR environment that is customised to each location it is used; the application can be deployed anywhere, so long as there is sufficient lighting for the spatial mapping to read the local area.

Figure 23: Mobile Configuration Screenshot

3.7. Evaluation of technical specification

To assess the technical efficacy of the two AR applications created for this study, both were evaluated against the criteria created by Krug et al (Krug et al., 2022) which proposed an evaluation grid for AR teaching and learning scenarios, which was dubbed AR-LSS. This criteria grid consists of the following parameters:

1. Immersion
2. Interactivity
3. Congruency with Reality
4. Contextual Proximity to Reality
5. Adaptivity
6. Gamification
7. Complexity

By utilising these criteria, the applications can be compared both against one another, and also against other AR learning environments from other pieces of research. A potential limitation of this method is that the definitions use language that is subject-specific to the field of science, but it is possible to translate it over to other fields, such as the field of history in the case of this study. As per the example provided by Krug et al, the parameters are visualised in a heptagon for both applications.

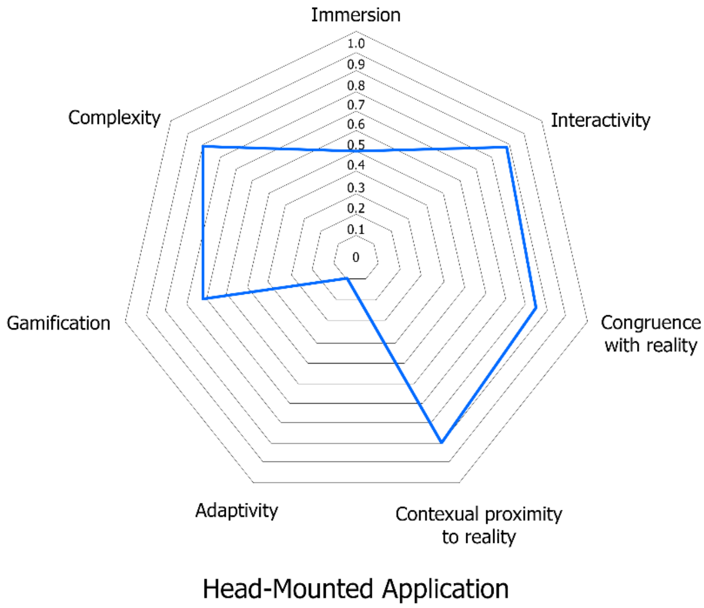


Figure 24: Head-Mounted Evaluation Criteria

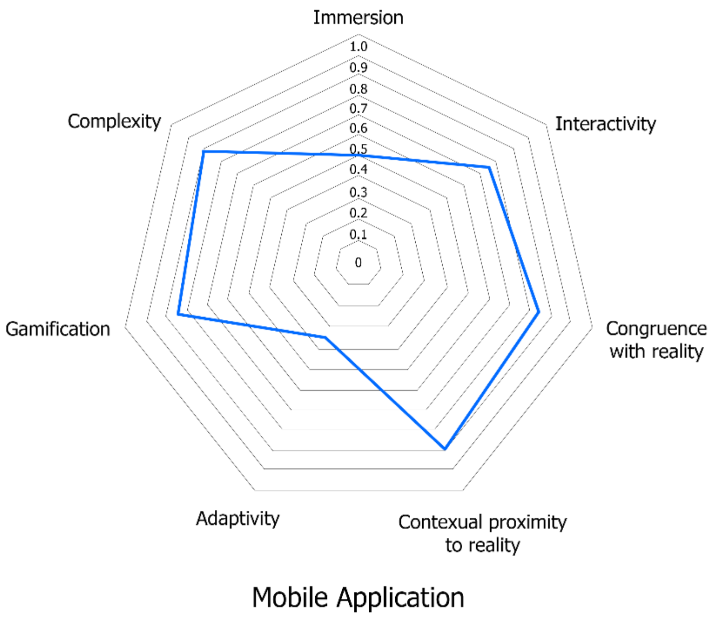


Figure 25: Mobile Evaluation Criteria

Although both applications contained the same educational content and even the same virtual assets, the parameters were subject to slight variance due to the methods used to implement the learning material. The mobile application scored a little lower on the Interactivity when compared to the HMD build due to the simplified control scheme which limits potential interactions, however the mobile build scored higher on the Adaptivity scale due to its ability to dynamically adjust the placement of objects with the spatial mapping functionality. Additionally, the mobile application scored slightly higher in the gamification category, as the inventory system of the player could be interpreted as a scoring system for the purposes of measuring progress through the experience. Both applications are lower scoring for the Immersion category, which is something that could potentially be expanded on in future research projects, however immersion was not a priority for this learning experience.

3.8. Data Collection Methodology

Previous considerations discussed the technical implementation methods for the project; however considerations must also be made for the collection of data and the types of data that will be needed to answer the research questions. Within the context of the research questions, the goals of the study are to identify differences in learner outcomes from the use of AR on long-term memory retention, factoring in age, location and AR method as variables and so first it would be necessary to identify if quantitative or qualitative methods would be more appropriate. In an analysis of methodology types, Mcleod (Mcleod, 2023) defines these methods as *'Quantitative data is information about quantities, and therefore numbers, and qualitative data is descriptive, and regards phenomenon which can be observed but not measured, such as language.'* Within this understanding, considering that the research questions will require numerical data, such as test scores, to measure and analyse, it can be determined that the scope of this study will need to rely on quantitative data collection methodologies to answer rather than relying on observations. These may be useful within certain contexts (for example observing how users interact with the system may be beneficial to understanding user approaches to interfacing with the system), they are not within the scope of this study and so will not be needed to answer the research questions.

Additionally, another concern regarding the collection of data is GDPR as this study will require a follow-up test to track the results of participants over time to measure the rates of knowledge retention over time, which will require a method of contacting participants at the second interval. With regard to this there are two options; the first is to email participants with a link to a digital test, the second would be to mail out a physical test for them to fill in and send back. Both are viable options, however both of these would require collection of some form of personal data from participants; either an email address, or their name and address. Under GDPR Article 5(e) (Wolford, 2020) any personal data (including email addresses) must be stored for no longer than strictly necessary and as per Article 5(f) *'processed in a manner that ensures appropriate security of the personal data, including protection against unauthorised or unlawful processing and against accidental loss, destruction or damage, using appropriate technical or organisational measures ('integrity and confidentiality').'* This law will require any data collected to be stored securely and deleted when no longer necessary. Logistically, any data collected will need to be processed digitally regardless of the method used, and any data collected physically will need to be digitally transcribed. For the purposes of digital data storage, Microsoft365 would likely be the chosen method as it is both GDPR compliant (Microsoft, 2023) and it is the solution already implemented by The University of Staffordshire, meaning that no additional security measures needed to be taken to implement it and considerations for it could be freely recommend by the University's ethics board. Consequently, using physical media such as printed questionnaires would add another layer of vulnerability to the data collection that would need appropriate controls for and as such, it was deemed appropriate to remove any potential vulnerabilities to better protect participant data.

This is not without precedent; although the consideration was primarily made to protect participants, research on collection methodologies has identified that there is benefit to research from using digital collection methodologies. In a study on response rates, Ebert et al (2018) performed a comparison between physical and digital responses by creating a survey on help-seeking behaviour and sending it out to two groups, each sharing an equal sample size of 3600. The responses rates were 36.29% for the digital group and 45.99% for the physical group, indicating that physical surveys are more likely to have a higher response rate from participants; however it is important to specify that participants in this study were selected at random based on age groups and contacted using legal inboxes that are mandatory for all citizens in Denmark; consequently the invitation to this study was sent out unsolicited, which may not be indicative of response rates for participants who volunteer for a study prior to surveys being distributed. Furthermore, this study also analysed the cost factor of such a study and when accounting for variables such as costs, handling, dispatching and the work hours of the researchers in the study, the cost of a digital response was valued at €1.51 per respondent and €15.67 for a physical respondent, indicating that the overall cost for collecting responses is significantly cheaper when performed digitally. The other benefit was response rate; the paper questionnaires had enough missing values compared to the digital ones that it was identified as a statistically significant different, which suggests that digital surveys obtain more thorough responses from participants. Finally, this study was performed prior to the commencement of GDPR law and as such did not factor in the impact of the newer legislation on costs, however providing a secure storage medium was used in the study, the impact on the digital method would have been negligible compared to the physical surveys which would need additional storage and destruction requirements. Using this study as reference, digital survey collection is a more suitable method than physical media for the project, both for overall response benefit along with the security requirements of data handling.

In conclusion, both applications have been designed to utilise different variants of implementation methodology, one for a head-mounted device designed to increase immersion in the location environment, the other running off a mobile device that will be more familiar to users. Each will test for the same information and use the same content, with the only differences being the hardware that is used to interact with it. The head-mounted variant is theoretically more immersive and allows users to interact with AR content using their head to look around and their hands to interact with virtual manipulatives. The mobile version requires the user to hold up their mobile device as a lens for AR, with engagement managed via tapping on the screen to collect objects/press their respective UI buttons. Both will be compared to identify which was the most beneficial for memory retention purposes. Additionally, a control group will be employed to test the same knowledge against a traditional classroom learning experience with a PowerPoint presentation being delivered by a teacher, which will serve as a baseline for how much information is retained when no AR is used. Further information on how data will be collected will be discussed in Chapter 4.

4.
Data Collection

4.1. Collection Methodology

Each test collected the same data from each group; a multiple-choice questionnaire pertaining to the content from the learning experience. As each group covered the same content, they were all tested for the same data to determine which group had retained the most. This questionnaire was hosted through Microsoft Forms (Microsoft, n.d.) and deployed to participants digitally on two occasions; once immediately post experiment, and again after a three-month period. During the first round of data collection, the questionnaire was distributed to participants via a QR code that participants could access through their phones or tablets. The second time, it was sent out via an emailed link directly to the questionnaire using the email addresses they provided. On the second round of collection, a feature of Forms was used to randomly arrange the questions to ensure that participants were re-calling the subject matter rather than attempting to remember how they answered the previous time.

The questions within the questionnaire were presented as follows:

1. Whose likeness is depicted upon the five Reichsmark coin?
2. Which town was the hometown of Bernard Grunberg?
3. Who was the original owner of the Knaurs Konversations Lexikon shown in the learning experience?
4. Which belonging of the Frank family is depicted in the Learning Experience?
5. Which profession was Dorothy's father part of?
6. What was Bernard studying at college prior to the November Pogrom?
7. Which item of Ruth's was depicted in the learning experience?
8. What did Sigmar Berenzweig's dolls represent?
9. What was inscribed upon the children's coat hanger?
10. What did Hedi's father have to earn in order to travel to the United Kingdom?
11. (Multiple Choice) The ex-libris in the Knaurs Konversations Lexicon was designed to include which elements of the artist's life?
12. Why were Bernard's tools branded?

During the first data collection, participants were given the option to leave any question blank if they did not recall the correct answer and this was communicated to them prior to the questionnaire. Despite this, every single participant from each group still elected to select an option for each question, choosing to guess rather than confess they did not remember the correct answer. In the follow-up questionnaire, a fifth response was added to each question for "I don't remember", and participants elected to select this response rather than leave a question blank, which would have had the same result for the purposes of data collection.

The results from each test were compared against each other to identify which groups retained the most information overall and what the rate of decay was for retention. This data would then be applied to the research questions to identify which group had retained the most information and how implementation/location/age group had impacted on the overall results in an attempt to find correlations between method and outcomes.

Scoring was out of a total of twelve, with one point for each correct answer and no points for an incorrect/"I don't know" answer. The only exception to this was Question 10, which as a multiple-choice question required five correct answers. Consequently, a score of 0.2 was given for each correct answer to that question.

4.2. Sample Sizes

Each group recruited fifteen participants to be tested at their required locations. This decision was made in conjunction with the National Holocaust Centre & Museum, who were only able to accommodate a maximum of fifteen participants due to their exhibit size and surrounding logistical concerns with facilitating the research whilst other visitors would be present at the museum. Eleven of the fifteen volunteers attended the museum on the designated day of testing, and due to the logistics of travelling there along with transporting the equipment, it was not possible to arrange a second testing date to finish up the full sample of fifteen.

Additionally, there was a falloff of participants between the two data collection points as several participants did not undertake the secondary questionnaire. A mean of 75.9% of participants were retained across all four groups.

Group	Initial Sample	Retained Sample	Sample Retention Rate
Control (Classroom – No AR)	15	11	73.33%
Focus One (Museum HMD AR)	11	7	63.63%
Focus Two (University HMD AR)	15	12	80.00%
Focus Three (University Handheld AR)	15	13	86.67%

Table 3: Participant Samples & Retention Rates

In conclusion, the data collection was performed in two stages with a three month gap between each collection phase, with participants being quizzed on information related to artefacts at the National Holocaust Centre & Museum. Each group suffered attrition between collection points, with some participants opting not to complete the second questionnaire. The average sample retention rate was 75.9% across all four groups. The knowledge retention rates were then compared between each data collection point to identify retention rates and patterns, which will be discussed further in Chapter 5.

5. Results & Data Analysis

To answer the research questions, varying types of statistical analysis were required and so have been separated into different sections. Data from the experiments was subjected to ANOVA style analysis to identify if there were any statistically significant variances that could inform responses to the research questions. Within the context of this, the outcomes of data analysis will henceforth be compared against the research questions to determine how the outcomes can provide answers to them. The following data analysis elements of this chapter were published in *Hand-Controlled User Interfacing for Head-Mounted Augmented Reality Learning Environments*. (Challenor et al., 2023).

5.1. Does AR improve information retention rates when compared to a traditional classroom learning experience?

The raw data showed that the control group retained the most information in both stages of data collection and outperforming the focus groups at each intervals, an outcome that contrasts with the study by Billinghurst & Duenser (Billinghurst & Duenser, 2012a) that had previously indicated that the groups with AR should have performed better than the control group. The ANOVA analysis showed that statistically significant outcomes were found only during the immediate post-test and that none were found in the outcomes of the delayed post-tests. A statistically significant difference was found in the immediate post-test scores between Focus Groups One and Three but not for any other groups. There was also no statistically significant variation in the decay rates between groups when subjected to ANOVA analysis.

Outliers were present in the data, however as the data refers to test scores, these have been retained in the sample in an unmodified state. The test scores were normally distributed for all four groups, as assessed by Shapiro-Wilk's test ($p > .05$). Data is presented as mean ± standard deviation. The ability to retain information was found to be highest in the Control Group in both the immediate post-test (n=15, 9.50 ±1.45) and the delayed post-test (n=11, 6.09 ± 2.83), followed by Focus Group Two in both the immediate post-test (n=15, 7.84 ± 2.54) and the delayed post-test (n=11, 4.49 ± 2.25). Focus Group One followed on, initially outperforming Focus Group Three in the immediate post-test (n=11, 7.30 ± 1.95 compared to n=15, 7.06 ± 1.86), however the inverse was true for the delayed post-test (n=7, 3.57 ± 1.08 compared to n=13, 3.67 ± 1.49). Within the context of the immediate post-test data, the ability to retain information was statistically significant for different methods of learning, $F(3,52) = 4.408$, $p = .008$. Tukey post hoc analysis revealed that the difference in mean test scores between the Control Group and Focus One (2.19, 95% CI (0.094 to 4.30)) was statistically significant ($p = .037$), as well as the difference in mean test scores between the Control Group and Focus Three (2.44, 95% CI (0.505 to 4.375, $P = .008$) but no other group differences were statistically significant. When tested for homogeneity of variances using Levene's test for equality of variances, the immediate post-test results were found to have homogeneity of variances ($p=.485$) however the delayed post-test results did not ($p=.044$) and were consequently subject to a Welch

ANOVA. Under the Welch ANOVA, there were no statistically significant differences in the test score means for the delayed post-test, Welch's $F(3, 19.935) = 2.443$, $p = .084$.

Table 4: Post-Test immediate ANOVA table

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	52.717	3	17.572	4.408	.008
Within Groups	207.288	52	3.986		
Total	260.005	55			

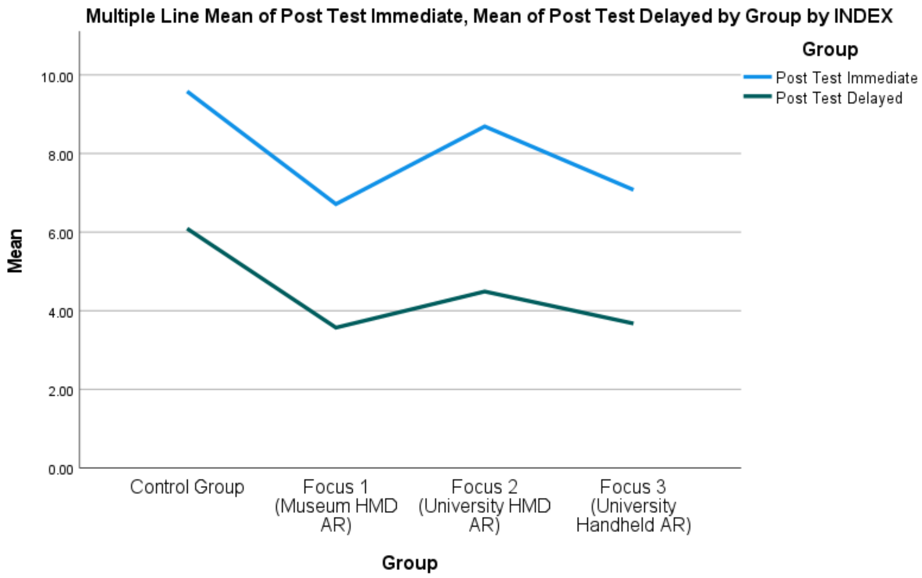


Figure 26: Questionnaire mean scores by group

The analysis shows little of statistical significance between groups aside from in the immediate post-test results, however the data averages do show clear performance results between groups. In both stages of testing, the control group performed better than the focus groups and was able to learn the most amount of information overall, however the information decay rate was lowest among Focus Groups One and Three, which suggests that although less information was learned from the initial experience than the control, more information was retained overall when AR was used. With regards to the research question, AR appears to be beneficial to retention rates for adult audiences but may not necessarily be as good for initial knowledge acquisition.

Outliers were present in the data regarding the test scores, with some participants having more varied performance than expected and one participant from the control group performing better on the delayed-test than the initial one. However, considering the testing was performed as a multiple-choice quiz, it is entirely possible that some participants elected to guess the correct answer rather than select the "I don't remember" option.

5.2. Does the Technology used to Implement Augmented Reality impact how much information Is retained? (Handheld vs Head Mounted)

The ANOVA analysis did not identify any statistically significant differences between the memory retention rates of the focus groups. Within the context of the average test performances, the participants from Focus Group Two learned the most amount of information overall, with groups One and Three having relatively comparable outcomes. Additional data is required to further substantiate the research but the outcomes of these experiments indicate that HMD solutions have the potential for higher amounts of initial knowledge acquisition rather than a handheld device as focus group two had the highest performance of the AR groups, and focus group one had the lowest knowledge decay rate of all four testing groups. However, as both groups One and Two utilised the same HMD application but had contrasting rates of test performances, it is likely that location and age are also impactful on learning outcomes.

The decay rate of information retained between tests was calculated using ((A/12) * 100) – ((B/12)*100) (A being the immediate post-test score and B being the delayed post-test score) with the output being considered as a percentage. Another one-way ANOVA was used to analyse if there was a statistically significant relationship between the testing groups and the average amount of information retained between tests. Outliers were once again present in the data; however, this data also pertains to test scores and so outliers have been retained in an unmodified state. The decay rate was normally distributed for all four testing groups, as assessed by Shapiro-Wilk's test ($p > .05$). Homogeneity of variances was identified using Levene's test for equality of variances ($p=.283$). Data is presented as mean ± standard variation. The decay rate is the lowest with Focus One (n=7, 26.190 ± 14.456), followed by Focus Three (n=13, 28.333 ± 16.722), then the Control Group (n=11, 29.090 ± 24.589), with Focus Group Two having the highest rate of decay (n=11, 35.000 ± 14.925). There were no statistically significant differences in retention decay rates between the different groups ($F_{(3,38)} = 0.414$, $p = 0.744$).

Table 5: Decay rate ANOVA table

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	421.525	3	140.508	.414	.744
Within Groups	12883.766	38	339.046		
Total	13305.291	41			

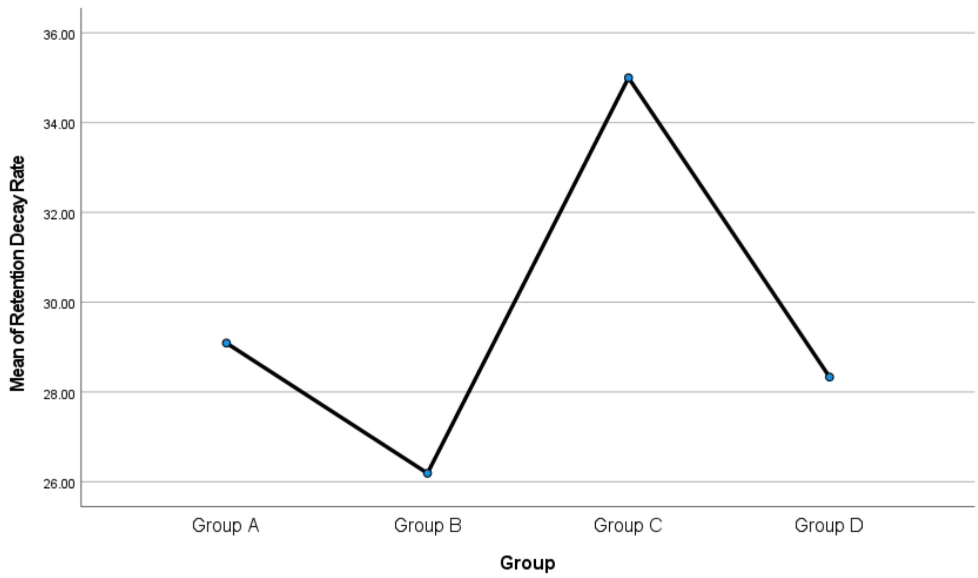


Figure 27: Retention decay rate by group

When considering the differences in results between the focus groups the variances identified in user performances do not indicate the AR methodology to be a contributing factor in the amount of data retained. The same AR configuration, when tested in two different environments, yielded both the highest and lowest rates of knowledge acquisition from the AR groups, along with the lowest and highest rates of decay respectively. The implication of this is that HMD AR has the possibility to outperform handheld methods for initial rate of knowledge acquisition, but other variables may be a major contributing factor to the efficacy of the technology for this purpose.

5.3. Does the Location of the leaner have any impact on the amount of information they retain? (Classroom vs Museum environments)

Due to the lack of statistically significant differences between testing groups, inferences must be made from the test score averages once again. Focus Group One, which was tested at the museum, scored the lowest on both the immediate and the delayed post tests when compared to the other groups which suggests that the University environment was superior for knowledge acquisition. However, Focus Group One also had the lowest decay rate of all four groups which suggests that although the lowest amount was learned from this group, participants from it also retained the most of what they had learned between testing stages. This potentially suggests that learning within a museum environment contributes toward knowledge retention, however the differences in retention rates between groups was miniscule and thus should not be considered as a major advantage to using AR in such environments in future.

As aforementioned, when testing the same AR configuration in two different environments, the results yielded the highest and lowest rates of data acquisition, and the inverse for the amount of knowledge retained. Visitors at the museum using the HMD learned the least of any of the testing groups, however the amount of that knowledge that was retained over the twelve week period was the highest of any of the groups, suggesting that the physical environment of the user is a contributing factor to the outcomes of an AR learning experience. However, to make the claim that the location alone is the key variable would be irresponsible considering that the age of the participants in both environments varied and so the data on age ranges must also be explored before drawing conclusions.

5.4. Does the age of the participant impact the amount of information retained from either method?

When subjected to a two-way ANOVA analysis, no statistically significant differences were identified between the test performances of age ranges, and it was found that the age of participants did not significantly impact information across age groups. The mean averages of each group can be visually compared along the graph (Figure 15) and the data indicates that performance was consistently better for all groups in the 26-29 age band. This was subject to some fluctuation along with some users from the lower age bands learning and retaining less than some of the older age bands. This potentially suggests that that participant age may not be as important to information retention as other variables.

The Information Retention Rate was calculated using ((B*100)/A) with A being the immediate post-test and B being the delayed post-test. A two-way ANOVA was used to identify if there were any statistically significant differences of how much information was retained between tests for different age groups, using the participant groups as the first independent variable and grouped age ranges as the second independent variable. A single outlier was present in the data but as it again regarded test scores, it remained in the data in an unmodified state as scores are an integral measure of the study and so removing scores would potentially alter the integrity of the dataset. The data was tested for normal distribution as assessed by Shapiro-Wilk's test ($p > .05$) and found that the data was normally distributed for all but one group, however this was left in an untransformed state(Laerd Statistics, n.d.) .There was homogeneity of variances as assessed by Levene's test for equality of variances ($P = .185$). The interaction effect between participant groups and age groups was not statistically significant, $F(6,27) = .566$, $p = .754$, partial $\eta 2 = .112$. Therefore, an analysis of the main effect of age group was performed, which also did not indicate that the main effect was statistically significant, $F(4,27) = .868$, $p=.114$, partial $\eta 2 = .114$.

	Type III Sum of Squares	df	Mean Square	F	Sig.	Partial Eta Squared
Corrected Model	6983.852*	13	537.219	.798	.657	.278
Intercept	90123.878	1	90123.878	133.893	<.001	.832
ParticipantGroup	825.552	3	275.184	.409	.748	.043
AgeGroup	2336.494	4	584.123	.868	.496	.114
ParticipantGroup*AgeGroup	2284.421	6	380.737	.566	.754	.112
Error	18173.839	27	673.105			

Total	153815.315	41				
Corrected Total	25157.690	40				

Table 6: Test of between-subject effects on retention rates against participant group and age group

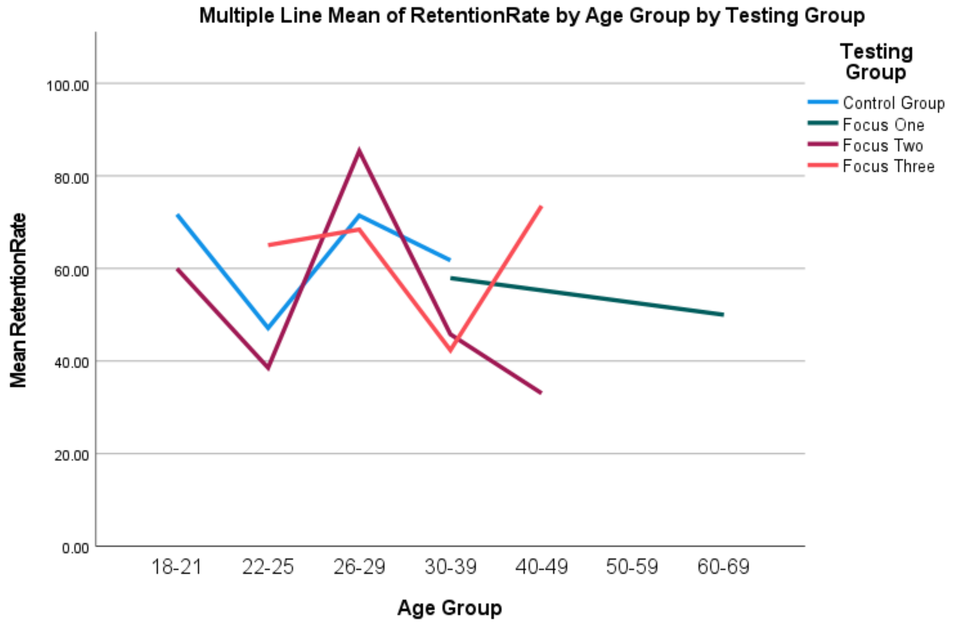


Figure 28: Retention rate by age group

An outlier was present again when analysing this data as the participant age range for the Museum focus group skewed toward older participants, with one participant being much older than the others (in their 60s.) This did not cause any aberrations in the analysis of the data however and demonstrated an expected decline in participant performance with age. As such the outlier was left within the data.

The age of the participants showed surprising fluctuation across several testing groups, with some of the younger participants attaining a lower overall performance than participants just a few years older. With the understanding of generalised cognitive decline over time (Murman, 2015), the general expectation would be that that the youngest learners would retain the most and the oldest participants would retain the least, however the results demonstrated that the highest rates of retention were most consistently achieved by those in the 26-29 age bracket (Figure 28: Retention rate by age group). Focus group one demonstrated this decline, but the other groups showed unexpected variance that suggests that knowledge retention rates may peak during the late 20s. This could imply that participants within this age bracket are either at a point of peak cognitive retention, or alternatively that learners within this bracket have a level of learning maturity that allows for the maximum amount of information to be retained. Additional data would be needed to further support this but the observation is interesting and unexpected.

The age ranges of the participants did vary further than initially expected due to the logistics of participant acquisition. Testing around the University environment resulted in the majority of participants being between the ages of 18-29, with exceptions for academics who participated in the study. The National Holocaust Centre & Museum had volunteered to recruit participants from their local area, however it was not until the testing period began that it was identified that these participants skewed toward older age groups. Consequently, the data, whilst it does demonstrate age performance with different methodologies, does not give direct comparisons between how similar age groups fared against one another across all groups. As such, it can be inferred that the 26-29 age band were the primary beneficiaries of AR learning methodologies, however additional data would be required to draw any definitive correlations from the data as obtained in this study.

In conclusion, data from both collection points was analysed and compared between all four testing groups using variations of the ANOVA analysis methodology. The results found that the use of Head-Mounted AR in a dedicated museum environment was overall best for retention rates (lowest rate of knowledge decay), however the same configuration also resulted in the highest rate of knowledge decay when deployed in a more generic environment (an empty VR testing lab at the University of Staffordshire). The use of a mobile AR experience resulted in less information retained compared to a HMD configuration deployed at a museum, but a higher one than when deployed in a generic environment, suggesting that mobile AR may be superior for more generalised learning applications, however additional variables may also be a contributing factor to this. The location of the learners did not provide any statistically significant outcomes and so whilst it can be speculated on, other variables must be considered, and further testing would be required to substantiate this point further. The age of learners also found no statistically significant differences in the amount of data retained. These findings will be discussed further in Chapter 6.

6. Conclusion

6.1. Introduction

In conclusion, this study sought to identify if the use of AR technology would be beneficial to the long-term memory development of adult audiences. The hypothesis was that the active engagement required to operate an AR system would increase the amount of knowledge retained by learners after using an AR learning experience, with the expectation that younger learners would benefit the most. This hypothesis would be tested using questionnaires and analysis of performance metrics both immediately after testing, and again after a delayed period. During the study, I explored variations of this concept to further interrogate the research questions and identify if any parameters would lead to a superior rate of memory retention. These parameters included the location of the learner, the method of AR implementation used to educate them, and if the age of the participant demonstrated any difference in the effectiveness of the implementation used, with the intention of further expanding upon existing knowledge in the field of AR for education and how it may be best utilised to provide a lasting educational impact on learners.

6.2. Summary of Key Findings

Data collected from the testing of the methods identified that despite participants having the highest initial rate of information acquisition from a traditional classroom learning experience with a statistically significant difference in test scores, the overall rate of retention was highest for the group that utilised AR within the Museum environment. The lowest retention was for the group that utilised the same setup within the University environment, which suggests that the physical environment of the user will impact the efficacy of an AR learning environment, however this data produced in this study was not found to be statistically significant toward this end. The methodology variations demonstrated that users with the HMD AR located at the museum had the highest rate of information retention, followed by the group that used mobile-device AR. The group using the HMD AR at the University had the lowest rate of information retention of all four groups. The age ranges of all participants were tracked and the data suggested the participants between the ages of 26-29 had the highest rate of retention of all age groups, which is consistent with the findings of previous studies on age ranges for knowledge retention (Rubino et al., 2015).

Statistically, the results that demonstrated significance were the initial test scores of the participants in the control group, as they performed noticeably higher than the other groups and ingested the most initial information from their learning experience. This was the case for both the Museum HMD and the University mobile-device groups as the differences between initial scores between the control group and these groups was statistically significant. These were the only statistically significant differences found across all datasets.

Age ranges did not show any statistically significant differences between groups or testing methodology, with most groups demonstrating fluctuating retention rates between age groups. Only focus group 1 showed a linear falloff as anticipated by the hypothesis; all other testing groups demonstrated variances with some later age groups performing better than those that preceded them. Most notably, participants between the ages of 22-25 had lower rates of retention than those in the 26-29 bracket.

Within the context of the research questions, the results of the testing found that the use of AR technology was superior to traditional education for memory retention, with two of the three methods demonstrating a lower rate of information decay than the control method, although the initial volume of knowledge acquisition was highest among participants from the traditional classroom experience. This supports the hypothesis that active engagement through AR typically results in higher retention rates. The physical environment of the user indicates that the surroundings of an environment played a contributing role toward the amount of knowledge retained, as the same system when deployed at both the Museum and the University found that participants of the Museum focus group, whilst having a lower initial volume of knowledge acquisition, retained significantly more than the University focus group, which again supports the hypothesis that the location of the user is another essential component to maximise the impacts of an AR learning experience. The method of implementing AR was only shown to demonstrate a minor result when testing for the efficacy of the technology used, as the participants who used a mobile device performed slightly worse than those at the museum, but better than those with the HMD at the University. Data from this experiment does not show any statistically significant differences and so it is inconclusive whether a mobile method is superior or inferior to a HMD solution. The age ranges of participants were expected to demonstrate a linear falloff regarding knowledge retention rates, however the results identified more variation than anticipated, with some younger age groups retaining less than some of the older groups. No statistically significant differences were identified, although the mean averages of each group performance indicated that the retention rates were highest among learners between the ages of 26-29.

6.3. Contributions to Knowledge

The research performed in this study make several contributions to existing knowledge within the field of AR for education, including practice and methodological advancements in understanding from the outcomes.

Firstly, with regard to methodology, the study sought to expand on the usage of AR to further develop interaction methodologies and means by which users can interface with HMD's by utilising gesture controls. Although other studies had sought to use similar gesture setups (Kyriakou & Hermon, 2019) to add naturalised user inputs, this came with a constraint to the users physical location; they were tethered to a laptop with no freedom to move or explore their environment, which is one of the potential benefits of using AR over other mediums. The solution outlined in this project sought to overcome this limitation by utilising an intermediary device and power bank to allow the user freedom to explore and interact with their surrounding environment in a manner that is unrestrictive and adheres to health and safety concerns; there are no tethers or cables that could cause harm to the user, surrounding individuals or damage to the local environment. The method by which this was achieved, using local area networking and a proxy device, is a new and innovative solution of which there is novelty and so future studies could seek to utilise it, or iterate upon it to further expand the realm of gesture imputs for HMD AR solutions. This is very necessary, particularly in the context of prior literature, such as the arguments made by Bujak et al that AR is useful at providing autonomy to users (Bujak et al., 2013), which is further compounded when barriers for accessing a system are lowered or designed to be natural for users and remove cognitive overload (Wu et al., 2013b).

Furthermore, although the design of the projected shifted away from emphasising it, the Augmented Window design is an innovation in the field of AR illusions and demonstrates a new and unique method by which users of an AR experience can have their experience made more immersive by expanding upon the physical limitations of their environment to add new depth to them, along with the potential for narrative experiences within the scope of the application. This makes another contribution to knowledge; one that may not necessarily be of direct influence to answering the research questions of this project, but nonetheless can be used to add novelty to a project.

Secondly, regarding the outcomes of the study, the data acquired was intended to satiate three areas of interest; the first was to further expand on the prior study by Billinghurst & Duenser (Billinghurst & Duenser, 2012a) to explore how much knowledge is retained over a prolonged period. The second was to explore how much information is retained by adult audiences of different age bands and how they compare. The third was to assess if HMD based AR or mobile-based AR would result in a higher rate of information retention. The fourth was to determine how the role of the environment impacts how much information is retained by an AR learning experience.

The prior work on retention followed a limited span of time, only tracking user responses spanning a four week period. This timespan, whilst sensible within the scope of its study, is very limited within an education context considering the duration of an academic year; for example if a learner is taught a concept in September, this study would suggest how much of that information was retained by October, however it would not indicate how much of that information would be retained by the date of an exam, which would be held either during January or June. For this reason, this study sought to further expand upon this knowledge to identify how effective AR is as a learning tool when compared to traditional learning methodologies, and found that in two out of three cases, learners had a higher rate of retention. This further signifies the efficacy of the technology, which may be used to inform further studies on pedagogical methodology and the field of TEL. However, the main limitation of such an experience is that users have no way of studying or revisiting the content of such an experience which is not an accurate reflection of how learning is conventionally structured; future lesson content in an academic year will typically build upon previous lessons, with students being given reason to, or at least encouraged, to revise content from previous classes. As such, a revised approach may be more beneficial, such as giving learners a way to re-engage with lesson content (Vavoula et al., 2009) or even revisit the application in a different context (StoryFutures China, 2023) if the design of the application permits it.

Regarding age ranges, prior studies on AR for learning typically focused around school aged participants (Cook, 2019a; Billinghurst & Duenser, 2012a; Zhang et al., 2022a; Yoon & Kang, 2021a)] as the connotations of AR learning suggest that it would be a tool for use within a school environment. However, HMD's are typically not designed for use on children, with the sizing of the headband being made for adult sized heads (Microsoft, 2021a) rather than children or teenagers. Because of this, any studies intending to use HMDs for children would require either a bespoke device or significant modification to an existing one; both of which were beyond the scope of this project and carry significant health and safety implications with a child audience as the focus of the research. Further investigation revealed little existing research in the field of AR learning for adult audiences, with almost all studies on the subject aiming for child audiences, save for a select few studies that also sought to include varying age ranges(Rubino et al., 2015). This displayed a remarkable lack of exploration, especially in a societal era where technological adoption is at an all-time high and wider ranges of demographics can benefit from available devices. This study explored this topic further to identify how much information would be retained by age ranges when utilising different methods and found that retention rates did not follow a standard linear decline as anticipated, but rather fluctuated among different age bands, with adults between the ages of 26 to 29 typically retaining more information than the younger groups. The outcomes of this aspect of the project will be beneficial to the research community for AR learning as it will serve to inform of the benefits to audiences that may be considered secondary audiences in some respects but could still utilise AR projects. Considering that museums and heritage sites are increasingly adopting AR and other immersive technologies to enhance their visitor experiences (Rubino et al., 2015; Yiannoutsoua et al., 2009; Sir John Soane's Museum, 2026; Museum of London, 2016; Oculus (Meta), 2018; Hsu & Liang, 2022), this may be useful in development of those resources to ensure they are educational and beneficial to visitors of all demographics.

Methodology for the implementation of AR remains a point of discussion, with studies often having to make a decision between pursuing either a HMD, a mobile-device, or an alternative methodology as appropriate. Conventionally, the benefit of using a HMD solution is the immersion factor; the user is looking directly at the AR content and it creates a very personalised effect for them, however the tradeoff is typically that the devices are expensive and can be difficult for new users to interface with. Mobile applications by contrast do not suffer from this effect as any user seeking to interact with an AR application will most likely be using their own device that they already know how to control, which mitigates both the interfacing and the cost requirements, whilst also having the rendering capabilities to achieve AR. The negatives of using a mobile device is the impact on immersion; the user will have to continually hold their device within their line of sight to witness the augmented content, and any interaction methods will need to designed around that constraint. Despite this, prior literature has little to directly compare the two, particularly with regard to education to determine if either achieves superior results. This project explored this dynamic and created two variants of the application, each containing the same information but presented with different design accommodations appropriate for each device and found that the results from testing each device were not statistically significant, with similar results obtained using both methods. Although the initial learning rate was highest for the HMD solution, this was only true when testing at the University, which suggests that environmental role or participant age may have influenced the rate further than the technological medium. This information will benefit future research into the field of AR for education as it demonstrates that the method of implementing AR may not be as important as the external factors and as such may help to inform academics on which aspects of their research to prioritise. The only caveat to this would be if technology becomes outdated, as users typically react negatively to technology that is behind current generation devices (Vavoula et al., 2009; Choudary et al., 2009), meaning that each application needs to be designed with the knowledge that it is limited-time use, or subject to long-term maintenance to keep the hardware up to specification with user expectations.

Finally, the last area of interest to this study was on the physical location of the user. The main aspect of a AR project is to augment the world around the user to provide new information, new contextualisation's or new interactions, and as such the focus of an AR application is typically to enhance specific aspects of a physical location(Rocha & Lopes, 2020), unlike VR where the location of the user is irrelevant as their surroundings will be completely replaced anyway. Despite this, AR applications can theoretically function in any location, which lends to the possibility that an AR learning experience designed for a specific location may still hold educational value when used in a different location. This study sought to explore this by testing the same application in multiple locations, both at a museum and at the university, to identify if either would achieve a superior result. The difference between both was not found to be statistically significant, with the group at the Museum initially learning less, but retaining more of that knowledge over time than the group at the University. This suggests that the users presence in a thematically appropriate environment may contribute toward better knowledge retention rates, but additional factors, such as participant age, may be influential in the amount of information initially retained. This contributes to knowledge as although the results are not statistically significant, it does demonstrate the role the environment has in influencing both what is learned and how much is retained.

The findings of this study did not find any outcomes that would be considered an empirical contribution to knowledge.

6.4. Limitations

There were limitations in this study that need to be addressed to better inform the outcomes of this experiment along with advising future research. For example, the research in this study was themed primarily around the use of HMDs with gesture-based control systems and this implementation was used in two of our experiments. Consequently, the testing did not include a control test that utilised a HMD without gestured-based controls, therefore leaving a possibility that a HMD implementation without them could potentially yield a different range of results. Existing research on HMDs by Baumeister et al (Baumeister et al., 2017) has already suggested that the default input methodologies of HMDs, often bespoke for each device, could contribute toward cognitive overload and may result in users becoming frustrated with a system or unable to fully utilise it toward the desired purpose. Despite this, additional research may be required to fully explore the outcomes of interaction methods with HMDs.

Additionally, the complicated logistics of implementing gesture-based controls with a Microsoft HoloLens mandated that the participants had to wear all the required devices on their person. These devices are light in weight and did not cause disruption, not did participants report any discomfort although our method of placing them inside a backpack did cause special logistical compensations to be made by the participants as their movements had to be considerate of their backs. No overt hindrance was identified during testing, but the nature of this implementation could be problematic if attempts were made to implement it in alternate environments, such as a museum or a heritage sight where users could potentially collide with displays or exhibit content, and so future research could explore alternative methods of attaching the devices, such as with a holster or something similar. Additionally, although the devices did not overheat during testing, prolonged exposure to heat would impact the lifespan of the devices, and so an alternative solution with consideration for ventilation would benefit longer-term usage requirements.

The Microsoft HoloLens was the only HMD used during this research. This was due to two reasons; the first was hardware availability as the University already owned two HoloLens devices. A HoloLens 2 was planned for use upon their release, however they were unavailable for some time due to bulk purchasing by the US Military (Bach, 2021) and further delayed by the Covid-19 Pandemic, resulting in the original HoloLens model being the only one available within the span of the project. The second reason was developmental logistics; whichever headset was selected needed some level of support for a game engine such as Unity or the Unreal Engine, without which the development of any application becomes exponentially more complex. Alternative HMDs may result in different outcomes, particularly ones which do not suffer from the limitations of the HoloLens such as the narrow field of view. Further research should seek to explore if users learn more from alternative devices, or how different features can impact upon the learner experience.

Within the context of the system design for both AR systems, a limitation was discovered during the classroom control experiment. As this experiment was designed to simulate a traditional classroom learning environment, participants were permitted and encouraged to ask questions regarding any of the learning material. This lead to participants asking for additional context regarding the artefacts, such as the purpose of hat boxes or how the Kindertransport had influenced the refugee policy of the United Kingdom, particularly in regard to refugees from the Ukraine conflict of 2022. Within the classroom experiment, it was possible to provide answers to these questions where applicable, however this was not an option inside the AR learning environments as the virtual educator was programmed with a very specific set of knowledge but nothing more. This is a common limitation across virtual learning environments and associated research, however with the advanced made in Artificial Intelligence in recent years along with its deployment as a consumer-ready product, it is possible that the virtual educator could be enhanced with AI to allow for live responses to participant questions with real-time interfacing. This was not covered within this study, however future research could seek to explore this topic further.

Participants within this study skewed in age group depending on participant group and this was directly caused by the collection method used. As three experiments were performed at the University, participants were recruited from the campus in Stoke-on-Trent which primarily skewed toward an age band between 18 to 26, although a few participants were older. Due to the logistical constraints of arranging for participation at the Museum site in Newark (Nottinghamshire) and the difficulties in facilitating transportation of participants between both locations, the Museum staff instead offered to collect participants from their local area. The participants collected for this experiment were recruited from local community groups, which consequently skewed to an age band ranging from 30-59. Due to this, there was not an equal distribution of participant ages across groups and so further study may be required with better balanced groups to fully address how participant age can influence the outcomes of using AR for memory retention.

Additionally, another potential limitation of our participant collection is that we did not ask participants about their prior experiences with using AR technology prior to the experiments. Three groups were provided with AR applications and a short discussion of how to use it, however prior experience with similar technologies could potentially influence how quickly users were able to adapt to it, consequently meaning that they would be able to utilise the technology for its intended purpose without the effects of cognitive overload (Baumeister et al., 2017). In future research on the efficacy and impact of technology-enhanced learning systems, it would be beneficial for the research outcomes to investigate if prior experience with similar technologies could have influenced the results.

Participant responses on the outcomes of the learning experience were collected at the end of testing, however the participants opinions or feelings toward the experience were not recorded aside from any verbal comments made during the testing process. Consequently, this limits the results to quantifiable test scores and does not include any attitude responses to the interest or enjoyment of such a system. As this research focused entirely on adult audiences, I missed a potential avenue for exploration into the responses on such systems and what potential interest may be in developing further systems exclusively for adult audiences, or lack thereof. Future research could potentially explore this further to identify how much interest adult audiences have in utilising technology-enhanced experiences for learning.

Finally, whilst our research explored the impact of AR on memory retention for educational purposes, our research only explored the use of it on the topic of History education. This raises the possibility that our research, both the implementation methodology and our outcomes, may not be transferable to other subject areas. For instance, whilst interactions with virtual objects may be effective for teaching history with virtual artefacts, they might not be as beneficial for fields like mathematics or sociology where there may be less meaningful ways for users to manipulate virtual objects, or where alternative uses of the technology may be more appropriate than interactions. This is not a limitation stemming entirely from this study; a significant number of AR themed studies use history as their topic (Santos et al., 2014; Blanco-Fernández et al., 2014; Chang et al., 2015b; Harley et al., 2016b; Choudary et al., 2009; Herbst et al., 2008b; Keil et al., 2011b), which is only natural given the extensive range of history museums willing to participate in research studies such as these, however it does somewhat skew the outcomes of such research. Consequently, there are potential benefits or detriments to using AR or natural interactions for education that may need additional research to fully explore for a comprehensive understanding, particularly for other subject matters as some topics may greatly benefit from the same systems that are currently being used for alternative purposes. For example, sciences may benefit from visualisations of physics (Billinghurst & Duenser, 2012b; Yoon & Wang, 2014) or biological processes, mathematical concepts could be made to be interactive, etc. Additional research is needed to fully inform other applications of AR for different educational subjects.

6.5. The Future of HMD Solutions

During the development of this project, despite the equipment chosen to facilitate this research, changes and developments within the field of AR have been observed as part of preparation for future research. Although developments have been made with regard to the technical specifications of new devices, HMD's have not experienced the economic growth as expected by the tech industry, and many are beginning to doubt in the future of HMD based solutions.

The Microsoft HoloLens continued development over the duration of the project, with the HoloLens 2 releasing in 2019 and being sold for $3499 USD (approximately £2766) but being unable to acquire due to an extensive contract by the US Military (Bach, 2021) preventing availability for consumer sales. Although this was an initial success, collectively both iterations of the device had only sold an estimated 300,000 units as of 2022 (Sinclair, 2022), causing Microsoft to cancel the third iteration of the device. The following year, Microsoft proceeded to cut most of their development team responsible for the HoloLens (Corden, 2023) and then further cut their development team again in June of 2024 (Bishop, 2024). This suggests that although the HoloLens division hasn't been fully dissolved, there may not be any subsequent iterations of the hardware.

Similarly, in March of 2023 Google announced that Google Glass would be officially discontinued in (Clark, 2023), with support for any existing devices ending in September of that year. Although this was the definitive end to the Google Glass project, it only impacted businesses and academics, as the consumer version of Google Glass was discontinued prior to this research project back in 2015 and only Enterprise editions being sold after for $999 USD (approximately £789) each.

Additionally, Magic Leap also announced its discontinuation of the Magic Leap 1 HMD in 2023 (Heater, 2023), suspending all sales of the hardware immediately, with the company pivoting away from commercial grade products and the gaming market toward Enterprise based solutions instead with subsequent models. Magic Leap also announced that support for the Magic Leap 1 would be terminating on December the 31st 2024. This was not the only announcement however, as the end of support also meant the termination of the key cloud services required for the device to function, meaning that as of January the 1st 2025, it will no longer be possible to use the Magic Leap 1 in any capacity and rendering existing headsets defunct. The headsets had retailed for $2295 USD (approximately £1814).

In 2024, Apple entered into the AR market with their new device of the Apple Vision Pro, an AR headset that Apple market as "spatial computing" sold for $3500 (£3899 in the UK with VAT). Despite attempts at marketing the Vision Pro, the device did not sell as anticipated, with Apple reducing their sales figures for the first year from the original 800,000 to 400,000 (Kuo, 2024) within just four months of the launch of the device. Although this is only indicative of early product sales, this suggests that the market appeal for consumer grade HMD AR is lower than expected.

The purpose of this section is not to predict the future of HMD solutions, but rather to inform future research considerations regarding the use of HMDs. The market trends as indicated by these devices indicates that consumer interest is not yet high enough that the development of AR HMDs has long-term stability. This may be due to the pricing of the devices, consumer interest, or some other factor, however the reasoning behind this is not within the purview of this study and would require additional data to fully determine. What can be reasonably stated however is that individual HMDs may not have long term sustainability as resources for research until the market stabilises, as they may lose support, or even their entire functionality, without much warning. Until market stability is achieved and consumer interest improves, any new users may be subject to cognitive overload (Wu et al., 2013a), thus mitigating the efficacy of any HMD based solution. It may be more suitable for future research to continue exploring mobile-device solutions until market stabilisation is achieved, particularly when factoring in the price of HMD's compared to mobile devices.

6.6. Future Research

Future research into this field will invariably be impacted by developments within the field of Artificial Intelligence. Previously in Chapter 3, it was discussed how one of the primary advantages to a classroom learning experiences was the role of the educator; how a living person acting as a teacher can be utilised by students to further explore topics and ideas in the form of asking questions. Through this advantage, information that isn't covered within the scope of a class or a learning experience can be further expanded on by learners who wish to know more about any given topic, providing the educator has the knowledge to either answer the question, or to appropriately direct the learner toward relevant learning resources. Within an AR or VR learning experience, virtual educators can only provide the information they are programmed with without any means of further expanding on this without requiring the application designer to update the program. However, recent advancements in the field of Artificial Intelligence (henceforth abbreviated to AI) have implications upon many sectors including education as the potential for how the technology can be utilised as a resource for learning is not yet known. If an AI could be utilised with a virtual educator, this limitation would not only be removed, but the potential for the learning resource would also increase by yet-unknown magnitudes. Hypothetically, users would be able to engage further with the virtual educator by asking questions directly related to the learning experience and could benefit from a wealth of knowledge that bypasses any generalised understanding of a given topic; the AI would theoretically be able to rival the knowledge of subject-matter experts. For example, the AI application CharacterAI (Character Technologies Inc., 2024) allows users to create characters, either custom or modelled after real-world figures and hold conversations with them, with the AI acting as the character. Given the versatile nature of the AI, it can be instructed to behave in a variety of ways, including being asked to provide elaborate or simplified answers as required by each user. This system can already be used as a virtual educator, with Albert Einstein serving as one of the default characters for users to communicate with. Initially this application was designed as a text-based chat system, later the developers incorporated an AI voice service to allow the characters to speak to the user, and as of June 2024, the mobile application for the service now allows users to perform live phone calls with the AI and allowing for more immersive conversations. If this technology could be incorporated into an AR or VR learning experience, this would bypass the aforementioned limitation of the role of the virtual educator and potentially create a more immersive and more stimulating learning experience for learners.

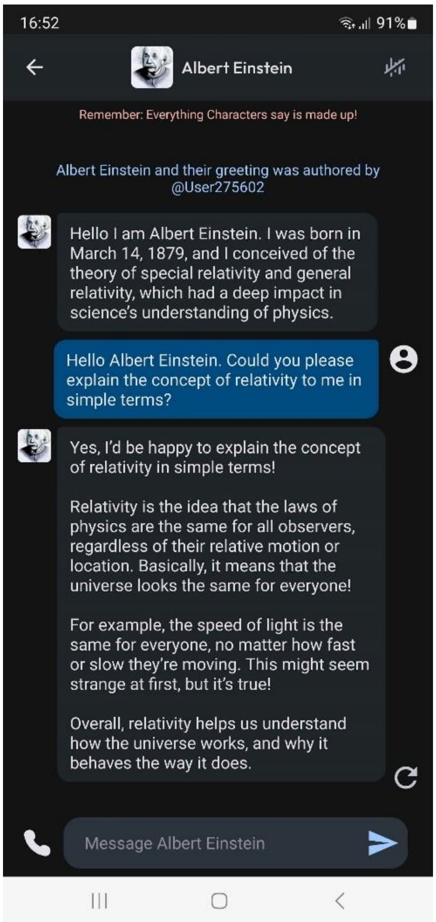


Figure 29: Character.ai conversation with Albert Einstein

The scope of this project only explored the use of AR for the purposes of creating a learning experience as it was necessary to utilise the facilities and resources available at the Museum, however future study into this subject could also expand into the field of VR to investigate its efficacy as a medium for virtual education for a range of audiences including adult age ranges. By exploring the same (or slightly modified as appropriate) research questions as this study, a more comprehensive understanding could be developed about the use of varying learning methodologies across a variety of audiences, as well as a different exploration of the concept of the location of the learner; in VR the user can be placed into a wide variety of virtual locations without physical constraints imposed by the real world, thus opening the possibility to explore if any particular kind of environment is more conducive to learning than others. For example, instead of structuring a learning experience around a classroom or a museum, learners could be educated in a forest or a penthouse apartment, a bowling alley, a space station or any other environment that would not otherwise be logistically feasible within the real world. Considering these requirements, it could even be possible to create an experience for a variety of environments and allow the user to choose one best suited to their own preferences to create a truly bespoke form of learning experience.

My future research will explore these topics to further develop understanding of how immersive technologies can be used to further benefit education for all age ranges, including adults and elderly learners who may wish to broaden their horizons.

6.7. Final Thoughts

Conducting this research has been a challenge significantly beyond what could have been anticipated, spanning multiple years, several supervisors and facing interruption from a global pandemic, significant obstacles have been overcome between the initial formulation of the research proposal through the writing of this thesis. It has pushed my understanding of the academic world to develop knowledge of how to read and write, ethical approval and application, submission of work for publication, systems design, data analysis and presentation of research outcomes. Overall, this study has made contributions to the field of Immersive Technologies for education, both with the methodology for system implementation and with the outcomes of the research questions and seeking to inform future research for both academics and for myself, for the projects I intend to begin in the aftermath of this study. I firmly believe the field of AR is still in its infancy, with technology enabling its progression but with so much potential yet untapped and it is my aspiration to collaborate with other researchers to fully push this medium into what I believe it can be.

When I began this project, truthfully, I was not certain if I had the potential to see it through to completion; the challenge felt too daunting and I frequently doubted my abilities, however, to quote the television show Angel (1999), "You never know your strength until you're tested". That feeling of being daunted never truly went away, and there were times when my convictions were tested, but every time things became difficult, each time a challenge seemed insurmountable, it was always the people around me who lifted me through it. My coworkers who were ever the bastions of rationality and knowledge, my supervisor who kept me motivated through the difficult times, the Unity Discord full of altruistic souls that were always willing to help with code, my fellow researchers who provided the much-needed comradery to share the plight, my friends who are the pillars that held me up no matter what, my family for providing their unending support, and my darling cat Crusoe who provided constant companionship through a global pandemic. This project is not just the sum of years of research, it is the byproduct of everyone who kept the fires burning through a very long night. And to all of them I wish to extend one final thank you, and the assurance that my future research is only going to keep building on what was achieved here.

7. Appendices

Appendix 1: Proportionate Ethics Form

Appendix 2: Participant Information Sheet

Appendix 3: Participant Consent Sheet

Appendix 4: Questionnaire

Appendix 5: Development Log

7.1. Appendix 1: Proportionate Ethics Form

Research Ethics

Proportionate Review Form

The Proportionate Review process may be used where the proposed research raises only minimal ethical risk. This research must: focus on minimally sensitive topics; entail minimal intrusion or disruption to others; and involve participants who would not be considered vulnerable in the context of the research.

PART A: TO BE COMPLETED BY RESEARCHER

Name of Researcher:	Jennifer Challenor
School	Games and Visual Effects

Student/Course Details (If Applicable)			
Student ID Number:		18021171	
Name of Supervisor(s)/Module Tutor:		Dr David White & Dr Yvan Cartwright	
PhD/MPhil project:	☒		
Taught Postgraduate Project/Assignment:	☐	Award Title:	
Undergraduate Project/Assignment:	☐	Module Title:	

Project Title:	Augmented Reality for Holocaust Education: Augmenting the journey of Kindertransport
Project Outline:	The future aim of this research is to explore the usage of Augmented Reality in a museum environment and to test its effectiveness on memory retention over a period of time. Prior studies performed on the effectiveness of Augmented Reality have been performed on

	short-term memory but not on long-term, leading to a gap in current research on the lasting impact of the technology. For the developmental stage, the Augmented Reality application needs to be created. The majority of the application will be created by myself in my office, however there are elements of development that require ethical consideration. As the application will feature a 3D human character, voice acting will be needed for the narrative. This process will involve hiring a voice actor online to remotely record the required voice lines and deliver them digitally. Since the last iteration of this document was written, the character of Leo has now been removed from the project. The only remaining character now is Gerald; an elderly man. The project will utilise an Augmented Reality application to create an interactive learning environment for the National Holocaust Centre and Museum. The Museum has a series of exhibits all titled "The Journey", which follows the story of a fictional child named Leo through the early stages of the Holocaust and leading up to the Kindertransport; a historical even in which approximately ten-thousand Jewish children were evacuated from German controlled territories to the United Kingdom. The Journey exhibits are designed for child audiences of Primary school age, which consequently leaves little educational value for older audiences. By utilising Augmented Reality, the goal of this project is to enhance the existing physical exhibit with augmented content to provide it with additional educational value for teenage and adult audiences. To test this, participants will be tested in four varying groups, with or without Augmented Reality in order to establish the impact of the technology upon memory retention. To further study the field, participants will also be tested inside one of three environments; either from their homes, at the Museum or at the University. The purpose of this is to gather data to analyse the impact of the physical environment upon memory retention, as the possibility exists that an Augmented Reality application may not need to be deployed inside of the

	museum; instead it may prove to be a useful learning resource when deployed inside a regular classroom.
Give a brief description of participants and procedure (methods, tests etc.)	Motion capture will be performed by either myself or Conor-Jack Moloy (the motion capture technician) within the university. There are already health & safety rules and measures in place for recording motion capture, as well as adhering to social distancing rules for Covid-19. Facial motion capture will be performed by myself at home. For the purposes of recording facial motion capture, I have purchased webcam software that allows me to record facial motion capture without the need for speciality equipment. Voice acting will be outsourced to a professional. Although a specific actor has not yet been chosen, there are many services for hiring a voice actor online who will record from their own home and send their recording files through the internet. No physical contact will be required and the voice actor will be paid for their performance. Participants for the research will be volunteering adults of at least 18 years old due to the physical requirements of the hardware; the HoloLens headband is designed for adult heads and consequently, it will not fit on children or teenagers. The design of the augmented exhibit is also intended to be educational for adult audiences, and so for these reasons it is only appropriate for participants to be 18 or above. Research will take place in the National Holocaust Centre & Museum in their exhibit "The Journey", and also at the University. Due to the covid-19 pandemic, two additional stages of testing are to be performed remotely for the purpose of ensuring safety. These are as follows:

	Museum Focus: Experience the exhibit with the Augmented Reality hardware. University Focus: Experience the Augmented Reality learning experience without the exhibit. Mobile Focus: Experience the Augmented Reality learning experience at home using a mobile phone application*. Remote Control: Attend an online lecture hosted on Microsoft teams. *Publishing an application to iOS is not possible without an Apple Mac device, which we currently do not have access to. Due to this, mobile testing candidates will be limited to Android users. Previously it was intended to host two lectures (one at the museum and one at the University) but due to the Covid-19 pandemic, it is not logistically feasible to arrange these whilst obeying lockdown laws. These tests will allow us to compare the results of the effect of Augmented Reality against traditional education, along with a secondary comparison about the role of the physical environment and how it may factor into learning with or without Augmented Reality. Upon completion, each group will be given an online written test hosted via Microsoft Forms containing the same questions to determine how much information was retained after their respective experiences. Following on from this, participants will be contacted again three months after their initial experience and asked to perform a secondary written test (performed online) to determine how much they retained over the three month period. Originally it was intended to collect email addresses from mobile participants to invite them to download the application from the Google Play store. However, after having reviewed this decision, it was instead decided that University owned mobile devices will be used instead to ensure a consistent performance for all participants.

	Some participants may be using older or newer hardware which could impact how well the application performs on their device. Participants with a poor performing device would not be receiving the same experience, and so instead University owned devices shall be used. This has already been cleared with the Henrion Media Centre. Participants will be asked for their age in number of years (E.G. 25) for statistical analysis to identify if there is a trend in Augmented Reality Enhanced memory retention performance based upon age. Dates of Birth have not been requested as this information is not required and could be considered collecting personal information. Statistical analysis from age will be published however due to age being collected in number of years, it will not be personally identifiable to any participant. Microsoft Forms will be used for the online tests. This system is functional and GDPR compliant as all data collected is stored securely in an online cloud service which is part of a University account. The only caveat to this method is that there are only two methods of providing access to a form; either internally within the University, or by generating a publicly accessible hyperlink that can be emailed to participants. To ensure that data collected is from participating members of this study, and also to track performance from test to test, participants will be asked to enter their e-mail address on the form. This will only be used for validation purposes and to track performance from test one to test two, the email addresses will not be published as part of the final data. In the unlikely event that a non-participating member of the study finds the form and fills it in, their questionnaire results will be discarded.

Expected Start Date:	January 2022	Expected End Date:	March 2022

Relevant professional body ethical guidelines should be consulted when completing this form.

Please seek guidance from the School Ethics Coordinator if you are uncertain about any ethical issues arising from this application.

There is an obligation on the researcher and supervisor (where applicable) to bring to the attention of the School Ethics Coordinator any issues with ethical implications not identified by this form.

Researcher Declaration

I consider that this project has no significant ethical implications requiring full ethical review	☒

I confirm that:		
1.	The research will **not** involve members of vulnerable groups. Vulnerable groups include but are not limited to: children and young people (under 18 years of age), those with a learning disability or cognitive impairment, patients, people in custody, people engaged in illegal activities (e.g. drug taking), or individuals in a dependent or unequal relationship.	☒
2.	The research will **not** involve sensitive topics. Sensitive topics include, but are not limited to: participants' sexual behaviour, their illegal or political behaviour, their experience of violence, their abuse or exploitation, their mental health, their gender or ethnic status. The research must not involve groups where permission of a gatekeeper is normally required for initial access to members, for example, ethnic or cultural groups, native peoples or indigenous communities.	☒
3.	The research will **not** deliberately mislead participants in any way.	☒
4.	The research will **NOT** involve access to records of personal or confidential information, including genetic or other biological information, concerning identifiable individuals.	☒
5.	The research will **not** induce psychological stress, anxiety or humiliation, cause more than minimal pain, or involve intrusive interventions. This includes, but is not limited to: the administration of drugs or other substances, vigorous physical exercise, or techniques such as hypnotherapy which may cause participants to reveal information which could cause concern, in the course of their everyday life.	☒
6.	The research **will** be conducted with participants' full and informed consent at the time the study is carried out:	YES ☒

	• The main procedure will be explained to participants in advance, so that they are informed about what to expect.	☒	N/A ☐
	• Participants will be told their involvement in the research is voluntary.	☒	
	• Written consent will be obtained from participants. *(This is not required for self-completion questionnaires as submission of the completed questionnaire implies consent to participate).*	☐	
	• Participants will be informed about how they may withdraw from the research at any time and for any reason.	☒	
	• For questionnaires and interviews: Participants will be given the option of omitting questions they do not want to answer.	☒	
	• Participants will be told that their data will be treated with full confidentiality and that, if published, every effort will be made to ensure it will not be identifiable as theirs.	☒	
	• Participants will be given the opportunity to be debriefed i.e. to find out more about the study and its results.	☒	
7.	A risk assessment has been completed for this research project		YES ☐ N/A ☒

If you are unable to confirm any of the above statements, please complete a **Full Ethical Review Form**.
If the research will include participants that are **patients,** please complete the Independent Peer Review process.

8. Information and Data Please provide answers to the following questions regarding the handling and storage of information and data:
a) How will research data be stored (manually or electronically)?

Data will be stored electronicallyvia OneDrive. The recording data will not contain any personal identifying information and the actors will be anonymous.

The data collected for creating this project is not personally identifiable, however within the interests of ensuring privacy is adhered to, the voice-acting data will be stored on an encrypted drive and will be deleted after the research has been concluded. Within the current timeframe, this is a period of roughly twelve months (allowing for additional data to be collected from the research if required).

The only exception to this is the email addresses. These will be stored on OneDrive and deleted as soon as the mobile testing stage is completed.

Data collected from the questionnaires will be stored on the University Onedrive via my login, which is not accessible to anyone except for myself. This is a GDPR compliant solution.

b) How is protection given to the participants (e.g. by being made anonymous through coding and with a participant identifier code being kept separately and securely)?

The only data being collected from participants (aside from their test scores) are their email addresses for later contacating and their age in years. The email addresses will not be published at any stage and deleted as soon as the second stage of testing is completed. The email addresses will not be kept longer than required and deleted immediately upon finishing testing.

c) What assurance will be given to the participant about the confidentiality of this data and the security of its storage?

Participants will be provided with an information sheet that details how data will be collected and stored.

d) Is assurance given to the participant that they cannot be identified from any publication or dissemination of the results of the project?

Participants will be informed via the information sheet about the purpose of the codenames assigned and how it will protect them from being identified, although as the data collected is purely anonymous there is no concern of identification from the results.

e) Who will have access to this data, and for what purposes?

Only myself and my supervisors, Dr David White and Dr David Cumming.

f) How will the data be stored, for how long, and how will it be discarded?

Data will be stored electronically via my OneDrive. Data collected from the questionnaires will be stored on the University Onedrive via my login, which is not accessible to anyone except for myself. This is a GDPR compliant solution. The data will only be stored until the research has concluded and the results presented in my thesis. When it is no longer required, it will be deleted from my OneDrive.

Supporting Documentation

All key documents e.g. consent form, information sheet, questionnaire/interview schedule are appended to this application.	☒

Signature of Researcher:	Jennifer Challenor	Date:	03/12/2021

NB: If the research departs from the protocol which provides the basis for this proportionate review, then further review will be required and the applicant and supervisor(s) should consider whether or not the proportionate review remains appropriate. If it is no longer appropriate a full ethical review form **must** be submitted for consideration by the School Ethics Coordinator .

Next Step: Students: Please submit this form (and supporting documentation) for consideration by your Supervisor/ Module Tutor. Staff: Please submit this form to your Head of Department or a Senior Researcher in your School. Once they have reviewed the form, this should be forwarded to the Research Administrators in RIIS (ethics@staffs.ac.uk) who will arrange for it to be considered by an independent member of the School's College of Reviewers .

PART B: TO BE COMPLETED BY SUPERVISOR/MODULE TUTOR (If student) OR Head of Department/ Senior Researcher (if staff)

I consider that this project has no significant ethical implications requiring full ethical review by the Faculty Research Ethics Committee.	☒

I have checked and approved the key documents required for this proposal (e.g. consent form, information sheet, questionnaire, interview schedule).	☒

Signature of Supervisor/ Head of Department/ Senior Researcher:	David White	Date:	7th December 2021

Next Step: Please forward this form to the Research Administrators in RIIS (ethics@staffs.ac.uk) who will arrange for it to be considered by an independent member of the School's College of Ethical Reviewers , having no direct connection with the researcher or his/her programme of study.

(Note: The section labelled Part C is not returned as part of the approved ethics documentation following submission. Confirmation of ethical approval was provided separately by email. The original template has been retained here for completeness.)

PART C: TO BE COMPLETED BY a member of the school's College of ethical reviewers

This research proposal has been considered using agreed University Procedures and is now approved.	☐
Or	
This research proposal has not been approved due to the reasons given below.	☐
Recommendation (delete as appropriate): Approve/ Amendments required/ Reject	

Name of Reviewer:		Date:	
Signature:			

Signed (School Ethical Coordinator)		Date:	

7.2. Appendix 2: Participant Information Sheet

STAFFORDSHIRE UNIVERSITY

Participant Information Sheet

Title of Research Project: *Augmented Reality for Holocaust Education: Augmenting the journey of Kindertransport*

Researcher: *Jennifer Challenor*

Supervision Team: *Dr David White & Dr David Cumming*

University School: Games & Visual Effects

Invitation: I would like to ask if you would be willing to take part in the following research. It is important for you to understand why I am doing this project and what it would involve for you if you decide to take part. Please take time to read the information carefully and take time to think about whether you would like to take part.

Your involvement in the research is voluntary.

You may withdraw from the research at any time and for any reason.

You can omit any questions you do not want to answer

Your answers will be anonymous, and the data will be treated with full confidentiality and that, if published, it will not be identifiable as yours.

You will be given the opportunity to be debriefed i.e. to find out more about the study and its results

What is this study about:

The purpose of this study is to research the impact of Augmented Reality on long term memory retention. This study is being performed with the National Holocaust Centre and Museum to enhance the story of the Kindertransport: the transportation of Jewish children from German controlled territories to the United Kingdom. This study is important as it exists for two purposes: the first is to research the usage of Augmented Reality technology for education and identify if it is favourably comparable to traditional education for learning retention. The second purpose is to create an interactive experience for the museum to help preserve a tragic period of history.

Participation in this study will include a learning-experience at the National Holocaust Centre & Museum, or at the University, as either part of the focus or control group. You will be educated on the story of the Kindertransport and the details of the individuals who survived the Holocaust due to it. This will be facilitated via either the Augmented Reality technology or by an educator depending on which group you are placed in. Following this learning experience, you will then be asked to take a digital test online via your smartphone or tablet to determine how impactful the learning experience was at educating you on this topic. This research will require to provide an email address by which you will be contacted at a date of exactly three months following this learning experience and asked to undertake a second online digital test to determine how much information you retained over this period of time. The results from all participants will be compared to establish the impact of Augmented Reality upon long-term memory retention against the impact of a more traditional educational method. You will also be asked to provide your age in number of years (e.g. 25) as part of research into the impact of age upon Augmented Reality Memory Retention. Your Date of Birth will not be requested as it is not required and would constitute as personally identifiable information. No personal information will be recorded nor published as part of this research. All data will be kept securely on a computer and deleted upon completion of this research. Email addresses will be stored securely in accordance with GDPR regulations and deleted as soon as testing is completed. Email addresses will not be published.

General Data Protection Regulation 2016 (GDPR)

Your data will be processed in accordance with the General Data Protection Regulation 2016 (GDPR). The data controller for this project will be The University of Staffordshire. The University will process your personal data for the purpose of the research outlined in this information sheet. The legal basis for processing your personal data for research purposes under GDPR is a 'task in the public interest'. You can provide your consent for the use of your personal data in this study by completing the consent form that has been provided to you. You have the right to access information held about you. Your right of access can be exercised in accordance with the GDPR. You also have other rights including rights of correction, erasure, objection, and data portability. Questions, comments and requests about your personal data can also be sent to the The University of Staffordshire Data Protection Officer. If you wish to lodge a complaint with the Information Commissioner's Office, please visit www.ico.org.uk.

FURTHER INFORMATION

This investigation will be undertaken for the purpose of completing a PhD research project at The University of Staffordshire. If you have any questions regarding this study then please do contact me via email. My email is Jennifer.challenor@staffs.ac.uk and I will be happy to discuss with you any questions you may have.

Thank you for taking the time to take part.

7.3. Appendix 3: Participant Consent Sheet

Consent form

Title of Research Project: *Augmented Reality for Holocaust Education: Augmenting the journey of Kindertransport*

I have read the information sheet provided and understand all the information included in it. I have had the opportunity to ask any questions about my participation in the project. My participation is voluntary, and I understand that I can withdraw my data from the study at any time without giving any reason or having any rights affected.

I hereby give my consent to participate in this project:

Name (please print):

Date:

Signature____

Email Address (Required)_______________________________________

I would like to be contacted again with the results of this study in 6 months (Yes/No):

____

7.4. Appendix 4: Questionnaire

Post- Experience Questionnaire

0) Please Enter your Email Address (*This is only for the purposes of validation and participant result tracking, this is not used for any other reason and any data collected from this question will not be published).

1) Please Enter your Age in Years (*This does not require your full Date of Birth, only your current age, for example, 25 years old. This will be used for statistical analysis on performance of age groups and will be published).

2) Whose likeness is depicted upon the five Reichsmark coin?

A) Joseph Goebbels B) Adolf Hitler C) Erich Hilgenfeldt D) Paul von Hindenburg

3) Which town was the hometown of Bernard Grunberg?

A) Lingen B) Koblenz C) Quedlinburg D) Meissen

4) Who was the original owner of the Knaurs Konversations Lexikon shown in the learning experience?

A) Susanne Pearson B) Erich Oppenheimer C) Otto Frank D) Ellen Rawson

5) Which belonging of the Frank family was depicted in the learning experience?

A) Dolls B) Suitcase C) Napkin D) Hat Box

6) Which profession was Dorothy's father part of?

A) Lawyer B) Woodworker C) Butler D) Optician

7) What was Bernard studying at college prior to the November Pogrom?

A) Woodworking B) Chemistry C) Law D) Photography

8) Which item of Ruth's was depicted in the learning experience?

A) Tablecloth B) Suitcase C) Dolls D) Coat Hanger

9) What did Sigmar Berenzweig's dolls represent?

A) Teacher & Student B) Doctor & Patient C) Father & Son D) Cop & Robber

10) What was inscribed upon the children's coat hanger?

A) Nur Bahnhof Verstehen B) Jemandem die Daumen drücken C) Bock haben D) Der Brave Kinde

11) What did Hedi's father have to earn in order to travel to the United Kingdom?

A) Passport B) Escape Training Certificate C) Writ of Passage D) Driving License

12) The ex-libris in the Knaurs Konversations Lexicon was designed to include which elements of the artists life? (Multiple choice)

- Religion
- Food
- Music
- Drama
- War
- Sailing
- Literature
- Heritage
- Driving
- Dancing

13) Why were Bernard's tools branded?

A) To mark his ownership B) A style choice C) To make them look second-hand D) To stop them getting mixed up

Answers:

2: D) Paul von Hindenburg

3: A) Lingen, Germany.

4: B) Erich Oppenheimer

5: C) Napkin

6: D) Optician

7: A) Woodworking

8: B) Suitcase

9: C) Father & Son

10: D) Der Brave Kinde / For the Good Child (Either answer acceptable)

11: B) Escape Training Certificate

12: Religion, Music, Drama, Literature and Heritage

13: C) To make them look second-hand

7.5. Appendix 5: Development Log

Development Log

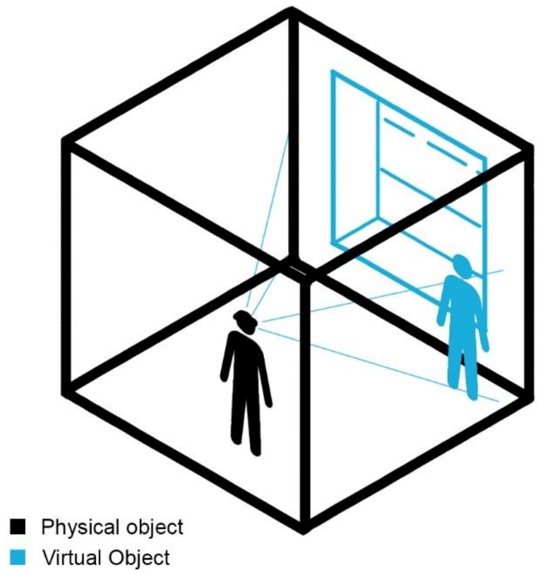
System Design Documentation

7.5.1 Table of Contents

7.5.2.1.1 Development Designs

7.5.2.1.1.1 Mission Statement

The intention of this system is to create an interactive Augmented Reality learning experience at the National Holocaust Centre & Museum to digitally preserve artefacts, testimonies and stories from the Kindertransport era of the Holocaust. Artefacts from this era are scarce and limited to only the personal belongings that survivors brought with them in their journey from occupied territories into the UK, hence why it is pivotal to digitally preserve them now along with the testimonies of survivors whilst they are still available. This Augmented Reality experience will utilise the Microsoft HoloLens to provide an immersive environment for learners, both in the physical museum and with the additional enhancements provided by the use of technology. The use of the HoloLens ensures a hands-free experience so that users may continue exploring and interacting with their environment without having to continuously hold up a hand-held device or adjust their positioning to see rendered content. As design elements of the application, the experience will feature interactive digital artefacts, a virtual character/narrator and a digital exterior window to depict daily life outside of the room. These components are intended to both inform the user of facts and events whilst simultaneously increasing the immersion value of the scene. Below is a diagram of the proposed concept.



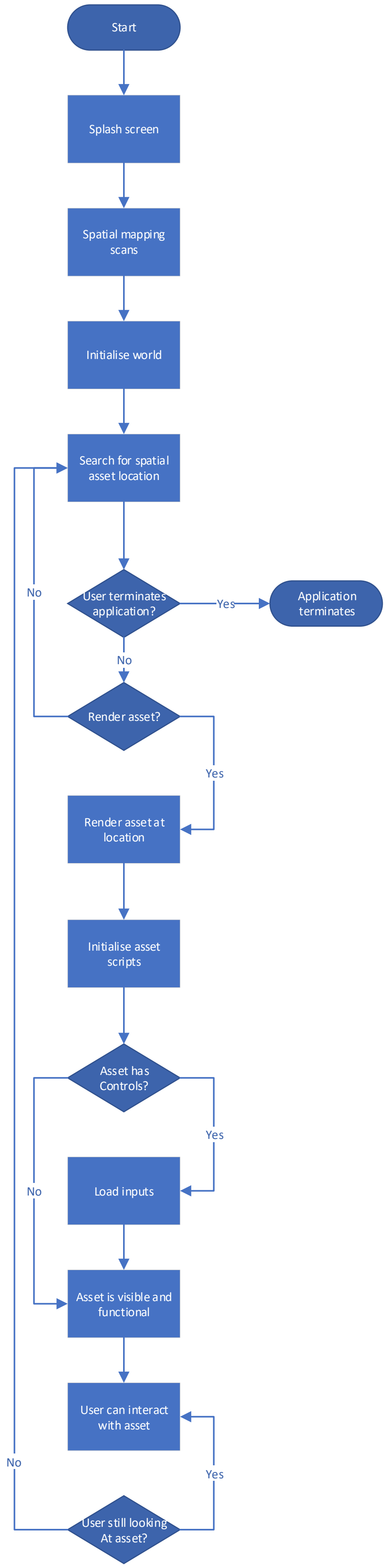
7.5.2.1.2.1 Objectives

These are the following design objectives for the application:

1. Render augmented reality components at designated locations within the environment.
2. Allow for interactions with artefacts including transformations.
3. Create and render a virtual character with the functionality to animate and talk.
4. Create a virtual window to demonstrate a virtual exterior.
5. Terminate upon specified command from the user.

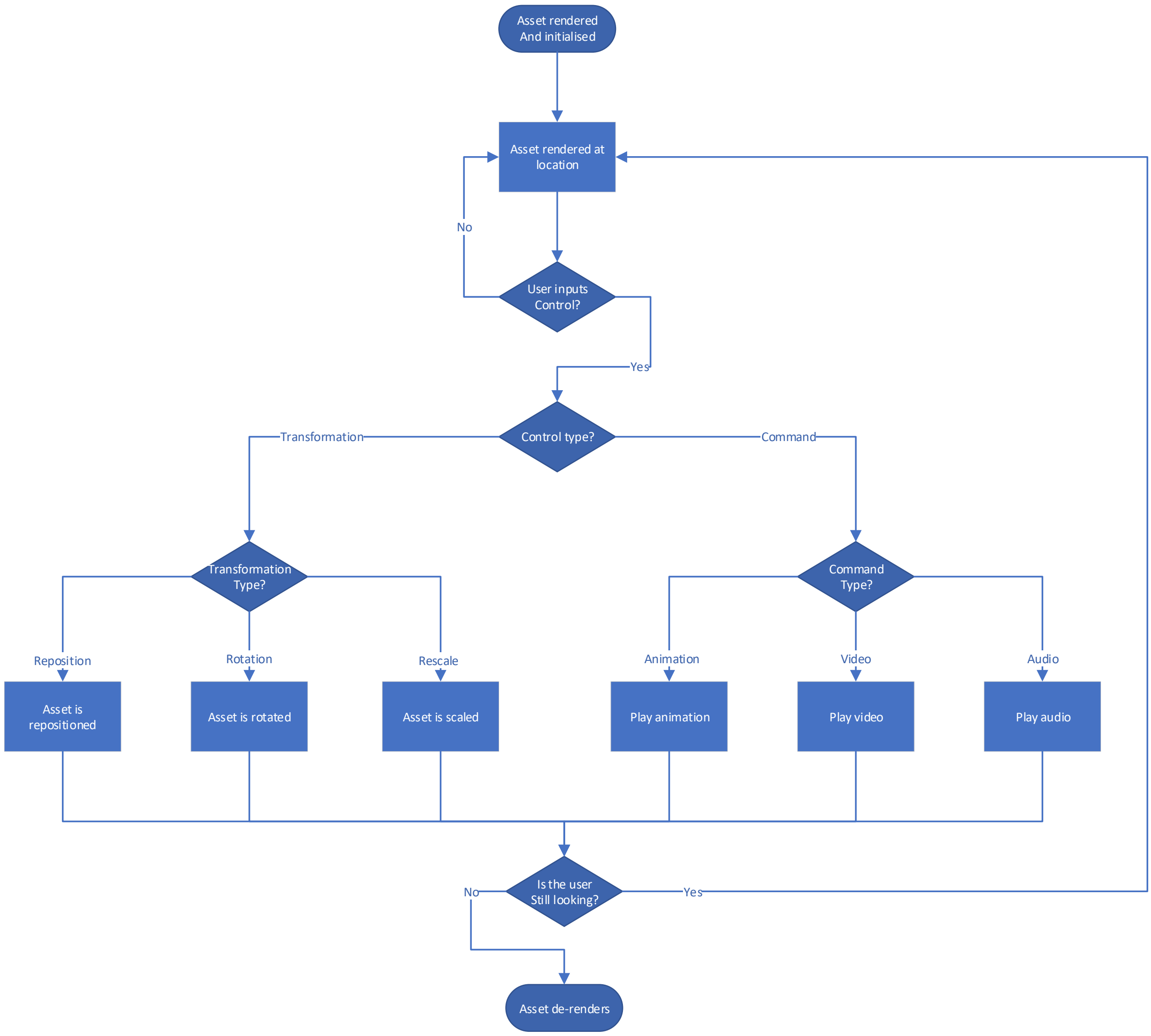
7.5.2.1.3.1 Overall System Design

The design of the application requires a continuous cycling of events with no definitive endpoint unless specified by the user that they wish to terminate it. Until specified by the user, the application will continually scan the surrounding environment to search for spatial mapping data and render assets in their dedicated locations for examination and interaction by the user. Upon an asset being rendered, its multimedia/interactive elements will vary depending on the purpose of said asset, however all assets will render upon being looked at and re-render when the user looks away regardless of any other functionality it may have. Each time a user renders an asset it will initialise its default state including size, rotation and location to ensure that it is always accessible, as it is theoretically possible for the user to transform a manipulative asset into a location that is inaccessible, such as scaling it to be too small or placing it in an area that is difficult to get into. This will occur in continuous prose until the user instigates the command to terminate the application, at which point all processes will end and the application will close.


Start
Splash screen
Spatial mapping scans
Initialise world
Search for spatial asset location
User terminates application?
Yes
Application terminates
No
No
Render asset?
Yes
Render asset at location
Initialise asset scripts
Asset has Controls?
Yes
No
Load inputs
Asset is visible and functional
User can interact with asset
No
Yes
User still looking At asset?

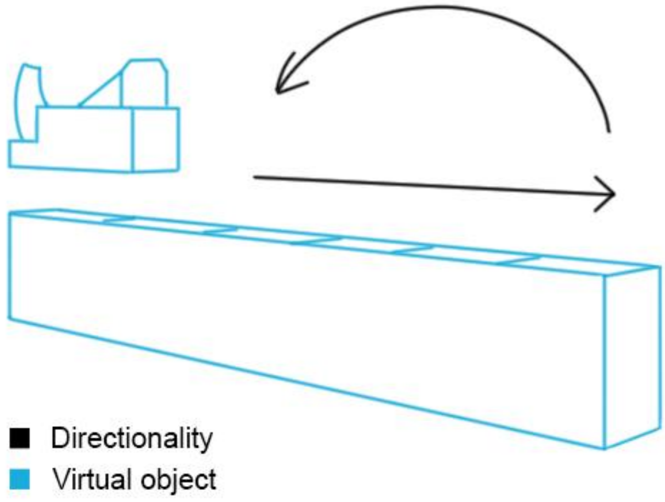
7.5.2.1.2 Interactive Props

Interactive prop assets will, upon being rendered, allow the user to manipulate them to reposition, rotate or rescale them for closer examination. These assets will be digitally recreated from physical artefacts using 3d modelling and laser scanning technologies to allow for interactions that would otherwise not be permitted. Functionality will vary depending on the asset as some may have animations or scripted interactions to further display their historical usage.



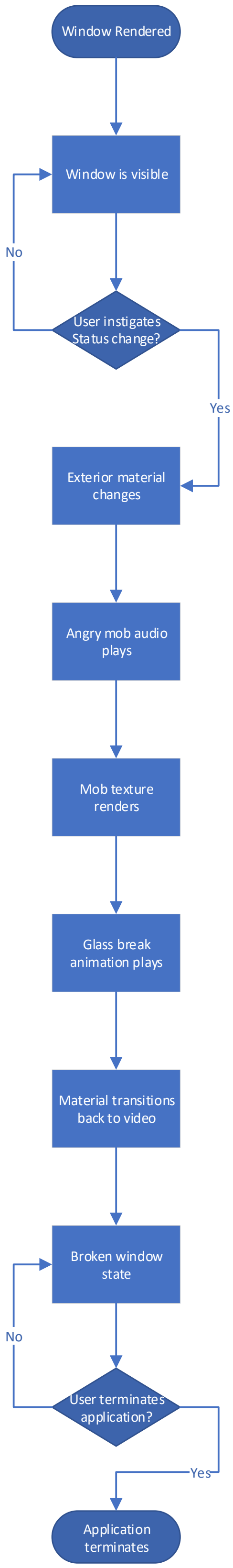
7.5.2.1.1.2 Plane Tools Minigame

To assist with depicting the usage of the plane tools, a minigame will be included to demonstrate their usage. This includes having the user guide a rendered 3d mesh of a plane tool over an unfinished surface of wood repeatedly until the surface is correctly planed down. This serves as both a demonstration of usage and an implementation of interactive learning as the user can do more with the artefact than simply examine it; this interactivity will be relevant to the research questions of comparing active vs passive learning.



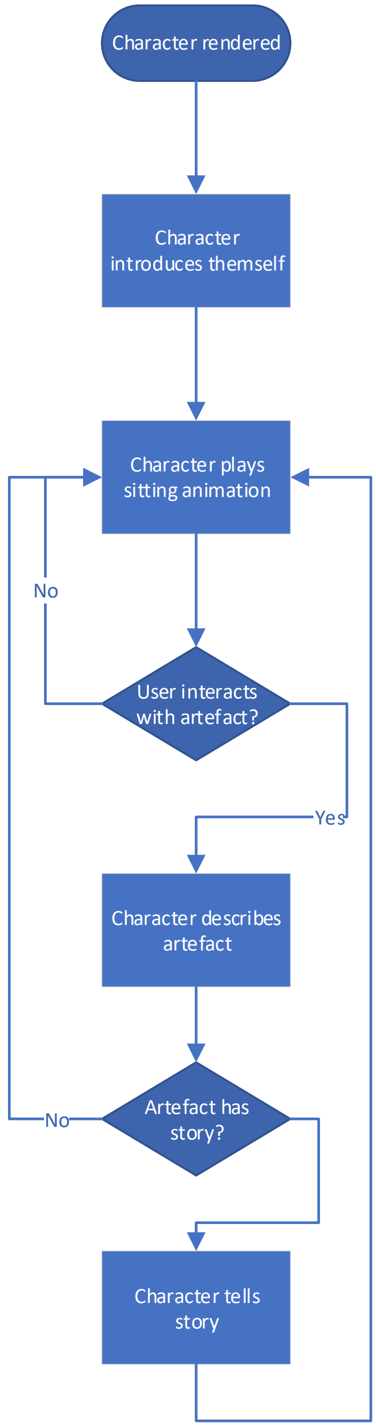
7.5.2.1.3 Window Prop

An AR window will be visible in the shop at all times on the exterior wall. When users look at this asset, they will be given an artificial view into 1930s Berlin with a video playing as a texture for the "outside". An interactive component is intended for the window to simulate the environment being vandalised during the night of broken glass. Upon being triggered by a user command, the exterior texture will be replaced with a night time texture of the street, a texture will be rendered of the silhouette of an angry mob, audio will play to depict angry yelling and the pane of the window will smash inwards, playing an animation of simulated glass destruction. Following this, the exterior texture will transition back to the street video but the debris will remain.


Window Rendered
Window is visible
No
User instigates Status change?
Yes
Exterior material changes
Angry mob audio plays
Mob texture renders
Glass break animation plays
Material transitions back to video
Broken window state
No
User terminates application?
Yes
Application terminates

7.5.2.1.4 Virtual Kindertransport Character

Inside the AR environment, a virtual character will be rendered to represent a survivor of the kindertransport based upon laser scans to reconstruct a real person. This character will sit upon a chair within the scene and speak to the user to offer input regarding the artefacts they interact with or tell stories about their experiences. This is to assist with immersion and to provide a more personalised form of storytelling that doesn't consist of reading paragraphs or watching videos.



7.5.2.1.5 Mobile Application

Due to the time constraints imposed upon this project by the duration of its sponsoring scholarship, research data from the HoloLens build must be collected in early to mid-2021. However, national lockdowns imposed to combat the Covid-19 pandemic are hindering collection of research data as travelling to the museum, deploying the equipment, and getting participants safely through the process is not currently a possibility. Providing the lockdown plan goes smoothly and tiered restrictions are re-introduced, deploying, and testing the HoloLens build should become a possibility once more. For the time being, the project must operate under the assumption that lockdowns could last longer than anticipated and thus pivot to find an alternative method of collecting relevant data to support the research project. To do this, a mobile version of the HoloLens application is to be created which will be deployed online for participants to remotely test on their own devices in their own homes.

7.5.2.1.1.5 Benefits compared to the HoloLens

There are some advantages to deploying to mobile as listed below:

- The mobile application is a Covid-19 secure solution as no physical contact or travel is required to test it.
- A mobile application lowers the cost of deployment to the museum as visitors would be able to load the application on their own devices rather than the museum having to purchase its own HoloLens.
- A mobile application increases the number of museum visitors who can utilise the application in future as groups would be able to download the application to their own devices rather than wait for the previous user to finish using the hardware.
- A mobile application can be tested anywhere by anyone with a device that can run it.
- Participants may have a lower barrier for entry as they will already be familiar with controlling a mobile device and will not have to learn its operation methods.

7.5.2.1.2.5 Detriments compared to the HoloLens

Whilst there are advantages to deploying to a mobile device, there are also disadvantages that must be mentioned:

- Participant control will be limited to touch-screen controls and potentially voice commands rather than the full hand-controls provided by the Leap Motion.
- Participant immersion may be negatively impacted by constantly holding up their phones rather than look around with their heads, as would have been provided by the HoloLens.
- Spatial mapping may be impeded depending on the quality of the users device.
- Performance may also be impeded depending upon the participants hardware.

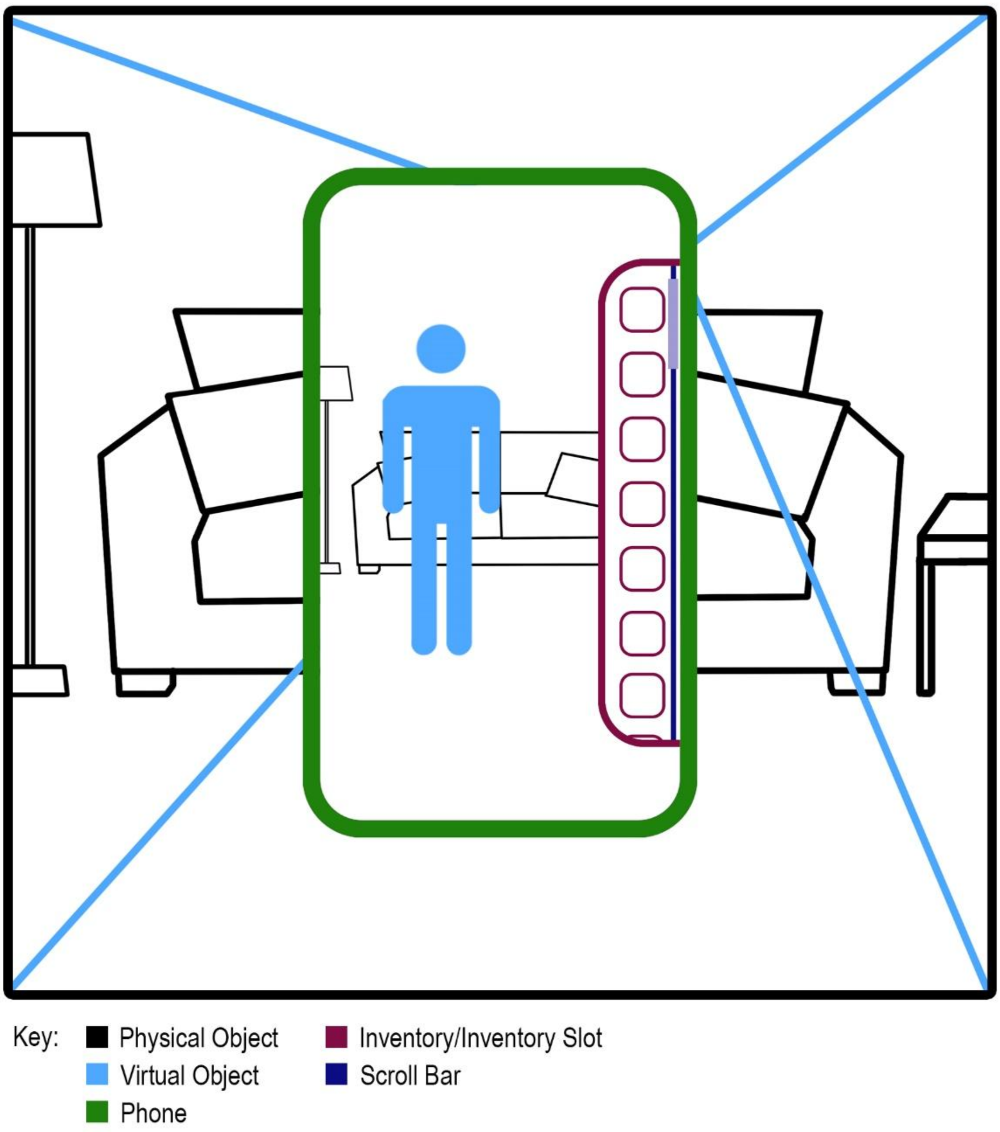
7.5.2.1.3.5 Limitations

The limitations of the mobile build are as follows:

- The application will only be available for Android devices; iOS requires compilation from a Mac which is not possible at this time.
- The application will have to be built with only native controls to a standard smartphone; extra peripherals cannot be used.
- Design of the environment must be standardised as there is no longer any control over the physical environment that the participant deploys the application in.

7.5.2.1.4.5 Mobile Operations

Given the limited range of controls available to the user, the previous design of having hand controls is no longer appropriate as deployment of the Leap Motion to each individual participant is logistically infeasible. Instead, the new application will have to be designed to natively work with standardised smartphone inputs such as the touchscreen and the microphone. To allow for the user to move around in real space and move virtual objects around within it, an inventory system of sorts will be required to allow the user to locate, pick up and give objects to the virtual educator.



As the user will not be able to pick up virtual objects with their hand, instead virtual objects will be scattered throughout the user's local environment and their task will be to locate them, tap on them when near collect them into their inventory, and then tap on an inventory item to give it to the virtual educator. Upon being finished with an item, the virtual educator will then place it back into the bottom of the user's inventory.

7.5.2.1.6 Developmental Milestones

Milestones for development will be recorded within this document, however crucial milestones have already been identified and must be reached in correct sequence.

7.5.2.1.1.6 Milestone One: Alpha

- All scripting functionality implemented. Core functionality working as intended.
- Assets present or sufficiently represented with primitive components.
- Bugs and errors may be present, however must not cause a crash or unacceptable detriment to user experience.
- All inputs/outputs must function as intended consistently.

7.5.2.1.2.6 Milestone Two: Beta

- All scripting functionality implemented and functional with minimal bugs.
- Code refined and refactored to increase efficiency, minimise memory usage and provide a seamlessly functional experience for the user.
- All assets must be included within the build and function as intended. This includes animations, sound effects, particles or other multimedia components.
- At no time must the application be capable of crashing or causing significant errors.

7.5.2.1.3.6 Milestone Three: Deployment

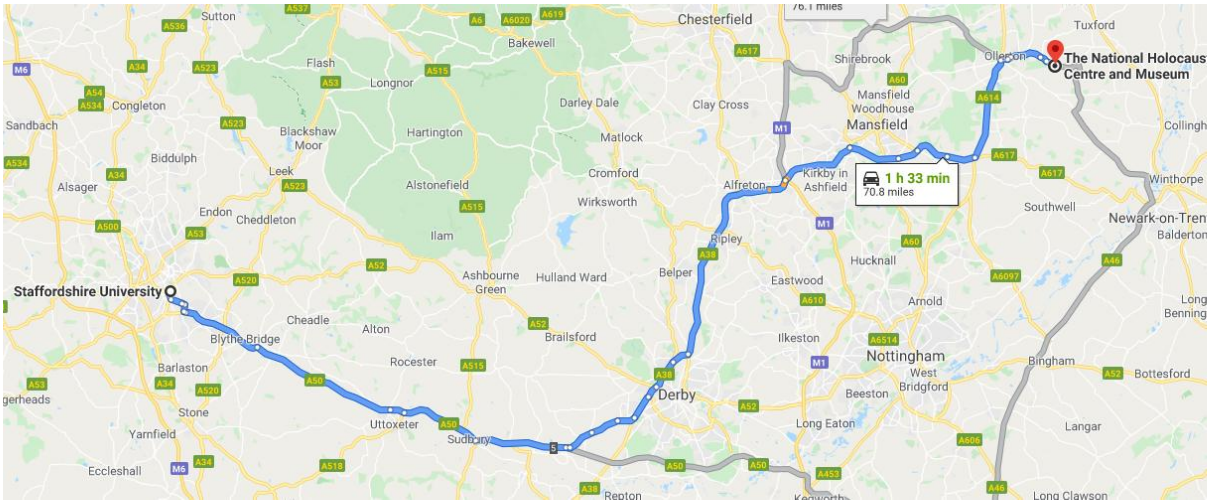
- All assets and scripts fully completed, implemented and polished as required.
- Code fully optimised for deployment.
- Users must be able to fully experience the entirety of the application without encountering any difficulties caused by errors, bugs or poor design decisions.
- Where possible, the application must be Schneiderman compliant.

7.5.2.1.4.6 Milestone Four: Maintenance

- Any newly identified errors, bugs or problems must be swiftly patched or alleviated however possible.
- The build must remain open sourced for new assets or content to be added if desired at a later date.

7.5.2.1.5.6 Logistical concerns

Development of this project is troubled by a concern of distance between the university and the national holocaust centre & museum; the University is based in Stoke-On-Trent and the museum is situated in Newark.



By car this route takes approximately 1.5 hours, however by public transport the journey took closer to 3.5 hours, having been required to take three trains and a 25- minute taxi from the Newark station to the museum itself. Because of this, transporting personnel or equipment (including the laser scanner and the HoloLens) from site to site will prove exceptionally difficult and at high risk of damage or loss of equipment. Transportation between both sites will be a requirement for the future of this project and will result in a car being a requirement for the project to continue. However, this can be alleviated with driving lessons and acquisition of a vehicle. As the equipment required is head mounted or handheld, and the personnel requirement always being lower than five, a regular five-door car will suffice for transportation purposes; a van or a minibus will not be required.

Driving theory test undertaken and passed on the 25th of February. A 30 hour driving course was booked immediately following the test.

First driving lesson undertaken 6th of March. Test booked for the 22nd of April.

Test was cancelled due to Covid-19 lockdown. A new test date will be allocated when the test centres reopen.

A new date was allocated to the 30th of June. Test has been cancelled again due to Covid-19.

As of the 23rd of July, test booking has been re-opened, but the Stafford test centre is still only accepting tests for key workers. Awaiting the opportunity to book a new test.

7.5.2.1.7 Development log: Assets

7.5.2.1.1.7 Asset List:

Knaurs Konversations Lexikon book

Window

Character model (TBD)

Coat Hanger

Jack Plane

Chisel Plane

Jointer Plane

Coins (TBD)

Pre-War Jewish Life Cloth

Pre-War Jewish Life Hat Box

Pre-War Jewish Life Napkin

Kindertransport Suitcase

Kindertransport Entrance Papers

Bernard's Blanket

Dolls

Escape training certificate

Gerald

7.5.2.1.2.7 Asset One: Knaurs Konversations Lexikon book

Began modelling the book using splines to determine correct shape of spine. Continued using splines to build the pages to utilise spline based animation later.

The spine has been built with a three point rig to control each segment and allow the book to open. Each block of pages is linked to a corresponding bone to open with the spine during the opening animation. The blocks of pages have been animated using spline based animation as can be seen here: https://www.youtube.com/watch?v=SbQrBw2mXpI&feature=youtu.be.

The same spline structure has been used to animate the pages turning. With a one unit offset, the page can open with the rest of the book, lay flat against a block of pages and then begin animating on frame 101. The result is exceptionally smooth: https://www.youtube.com/watch?v=KDkS32Rm4i8&feature=youtu.be

Error: Upon importing into Unity, the animations are not there. No import/export settings will fix the problem and testing the animation in different packages yields the same results, the animations aren't there. Asking in the Unity forum has found a result (https://forum.unity.com/threads/animation-not-fully-importing-into-unity.816894/#post-5414247), 3ds Max supports spline based animations but no other package does. Constraints of some variety are required for the engine to understand, meaning the current animations won't work. They will need either binding to bones or morph targets, and right now the morph targets seem more logistically sensible.

Update: The morph target system worked. By creating copies of the block meshes, morph targets could be created by deforming them and syncing up the morph timers with the animation timeline. The created result can be found at: https://sketchfab.com/3d-models/book-animation-test-7fb38563bbef401198d23779c065cca8

Update: I don't have any reference for the lexicon yet so I've instead put sketches of US presidents on the pages. The UVs work fine, I will be able to replace the textures with the ones we need when I have the correct scans/photos.

Update: I found some great reference for the cover of the Lexikon book so I've replaced that texture in Unity. There are still presidents inside there for now though.

The next step is to get the animations working inside unity with the leap motion controls.

Update: The leap motion controls were remarkably complicated to get working but it's now functional. The left hand controls the spine and the right controls the pages. There's only one page to flick through but it works!

Error: the morph target of the text blocks is resetting when I flick the pages. The blocks go from opened to the closed state which breaks everything. The page animations don't synchronise anymore. The problem seems to be occurring at clip level rather than inside the animation controller but I can't work out why. The Unity discord is perplexed too.

7.5.2.1.3.7 Asset Two: The window

Functionally simulated/baked glass shattering was created prior to the creation of this log, but massfx controls allowed for a rapid simulation that looks realistic aside from the sheer scale of the impact. Smaller individual breaks may be more desirable for the finished product.

Two windows were created, one using standard game screens and one with an optical illusion effect. Initially there were difficulties getting the window to render beyond the walls of the spatial area but the force override setting has fixed that issue.

Update: The glass smashing can be triggered with a voice command.

Error: the game window won't hide when using voice commands to summon different assets.

Update: the game window required a mesh renderer component for the script to function. It has now been fixed.

Error: The game window won't work as desired. The force override means that the exterior panel is visible through every surface, not just the window. The exterior should only be seen when looking out of the window frame but it can be seen from quite literally everywhere. Advanced unity rendering knowledge may be required to use this solution.

Error: The unwrap for the illusion based window is difficult to get right. A cube map is likely the most sensible approach to create a seamless exterior effect but creating one from vintage photography is going to be exceptionally challenging.

7.5.2.1.4.7 Asset Three: Coat Hanger

Began construction of the hanger using the photograph as reference for scale. The main body was built to low poly specifications and the hooks were constructed using spline based methods to create an accurate shape. The asset was successfully unwrapped and textured in substance painter.

Error: The fonts in substance are not accurate to the reference image, photoshop may be required to adjust the text.

7.5.2.1.5.7 Asset Four: Jack Plane

Construction of the jack plane began with using reference imagery provided. Wooden jack planes are now somewhat rare due to the prevalence of electronic equipment so finding alternate angles was difficult. The shape of the plane is several sections of unusual geometry but nothing too complex, however it did take a little trial and error to construct the handle. The handle requires curved geometry around most of it but a sharp edge and a flat face at the front which took some tinkering but it came out looking as accurate to the reference as is possible. With low poly conditions required for the HoloLens, additional curvature would require significantly more geometry and so will be avoided where possible. The tool was unwrapped as two material IDs as additional texel density was required and so UVs were spread out to two texture sheets.

Texturing of the asset took place in Substance Painter and was also something of a challenge to achieve the layered wood effect from the reference. The rest was done with the usage of generators and a little brushwork but for the most part this was a simple asset to texture. The branded initials proved a small challenge but ultimately was achieved with the Font tool and a little brushing to edit the shape of the lettering.

7.5.2.1.6.7 Asset Five: Chisel Plane

The chisel plane asset is one that is cloaked with uncertainty as the reference image only shows the handled, leading to speculation about what the tool actually was. Due to the other items being planing tools, it is safe to assume that it is the handle of a planing chisel. The handle was constructed from the reference image although proved to be a challenge due to the topology required to support the flat segment. The top section of the handle had to be flattened, extruded and vertices manipulated to create the curved effect and then re-curved back into the rear taper. The front section was modelled from a standard plane chisel and proportioned as such. After unwrapping the mesh was taken into substance painter and used the same presets to achieve the wood and brand effects. The metal visible on the reference imagery was heavily corroded and so this effect was applied to all metal segments uniformly, although it can be cleaned if additional imagery is supplied at a later date.

7.5.2.1.7.7 Asset Six: Jointer Plane

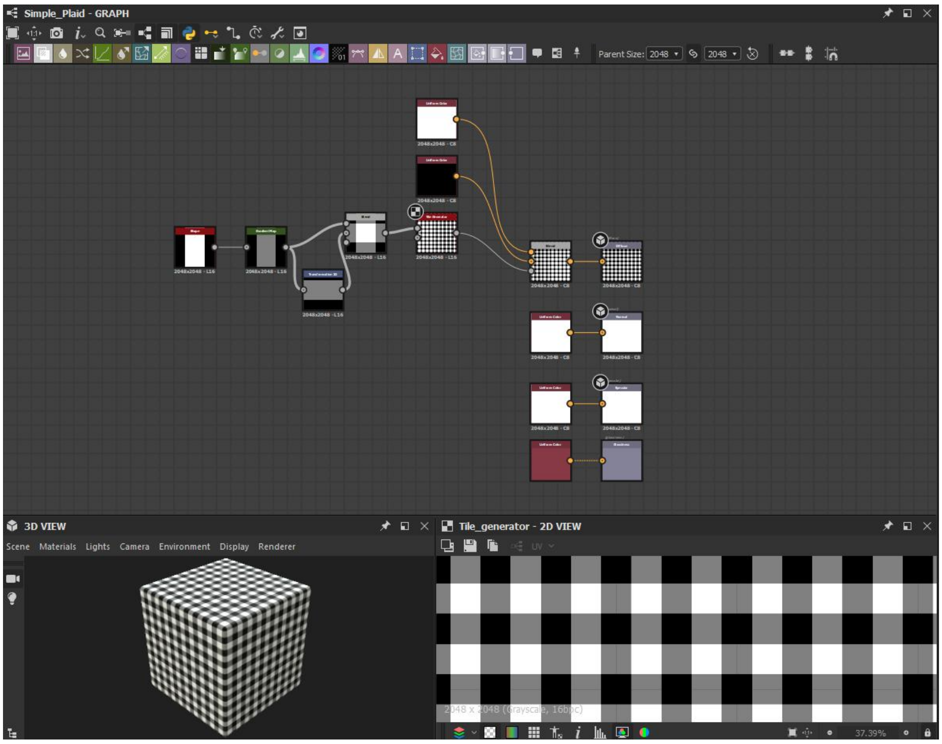
Acquiring reference for this tool proved difficult due to the various names and design iterations it has been known by over the last century, ranging from flat plane to tonguing plane and finally jointer plane. The design of this tool was similar to that of the jack plane only a little more simplified. Construction was assisted by the ability to duplicate elements of the jack plane but required a bespoke handle. The handle was tough to build as the complex geometry was more suited to a high poly subdiv workflow than regular poly modelling, but after some experimentation the shape was achieved. After unwrapping and exporting into substance designer, the material setup created for the jackplane was saved as a preset and used to create a base for the jointer plane, which was then amended with the correct procedural tools to create dirt and wear.

7.5.2.1.8.7 Asset Seven: Coins

Modelling coins from reference is a tedious task that usually involves excessive sculpting in zbrush or photoshopping into a functional height map. Instead of performing either interaction, the laser scanner was utilised to digitise a 10 reichspfennig coin owned by a coworker. The scanned components were then baked down onto a cylinder and textured in substance painter, a task that took a fractional amount of time when compared to alternative methods. The result is an accurately scaled and detailed coin with real-world wear and tear that would otherwise have to be simulated.

7.5.2.1.9.7 Asset Eight: Suitcase

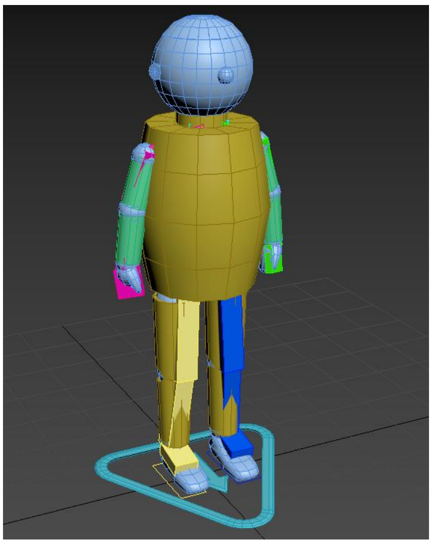
Modelling the suitcase without sizing reference was challenging because measurements had to be estimated by eye rather than created accurately. Consequently, elements of the case may require resizing at a later date to ensure accuracy. The case was modelled from the reference photographs provided by the NHCM, however the hinges of the case were not depicted in either photograph and so had to be built from reference found online of a similar antique suitcase. These may also require changing later for accuracy purposes. The interior of the case was textured using a custom graph built from Substance Designer that allowed for blending of two tones to create an accurate gingham pattern.



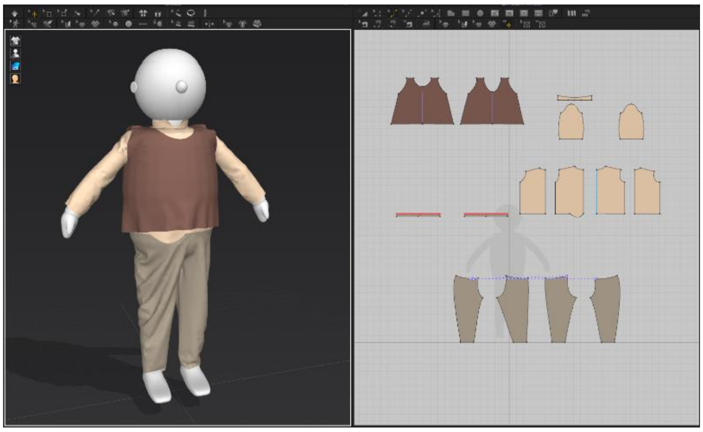
Lastly the case was rigged to a skeletal structure and animated to allow for additional interactivity later on. The case can be opened or closed with this animation sequence. https://sketchfab.com/3d-models/anim-suitcase-2b7f6f14e58d4999b4c18beac5f0f56c

7.5.2.1.10.7 Asset Nine: Doll – Man

Building antique dolls can be a difficult endeavour due to the underlying structure; when a doll is clothed, the rig they are built on cannot be seen. Based on an estimation due to the type of doll, it was assumed that the doll was built on a ball-jointed rig that would allow for simple posing. This rig was constructed and bound to an animation skeleton for the same purpose.



The face of the doll requires two approaches, both sculpting and texturing for the eyes and facial hair respectively. The clothing of the doll proved a significant challenge because of the underlying skeleton: clothing slopers are designed for a human body but the body of dolls does not accurately follow each curve or contour, meaning that standard slopers would prove ineffective. Instead the outfit had to be created by trying to imagine what the toymaker would have done when creating the outfit with small quantities of low grade fabric.



The outfit is a little too baggy but adjusting the sloper doesn't alleviate this concern. Instead, adjustment of simulation properties will likely be required to get a more bespoke fit. Minor adjustments were made and the outfit was cleaned up in Zbrush to remove un-necessary folds and simulation errors. Afterwards the asset was retoplogised, unwrapped and subsequently textured using Substance Painter:

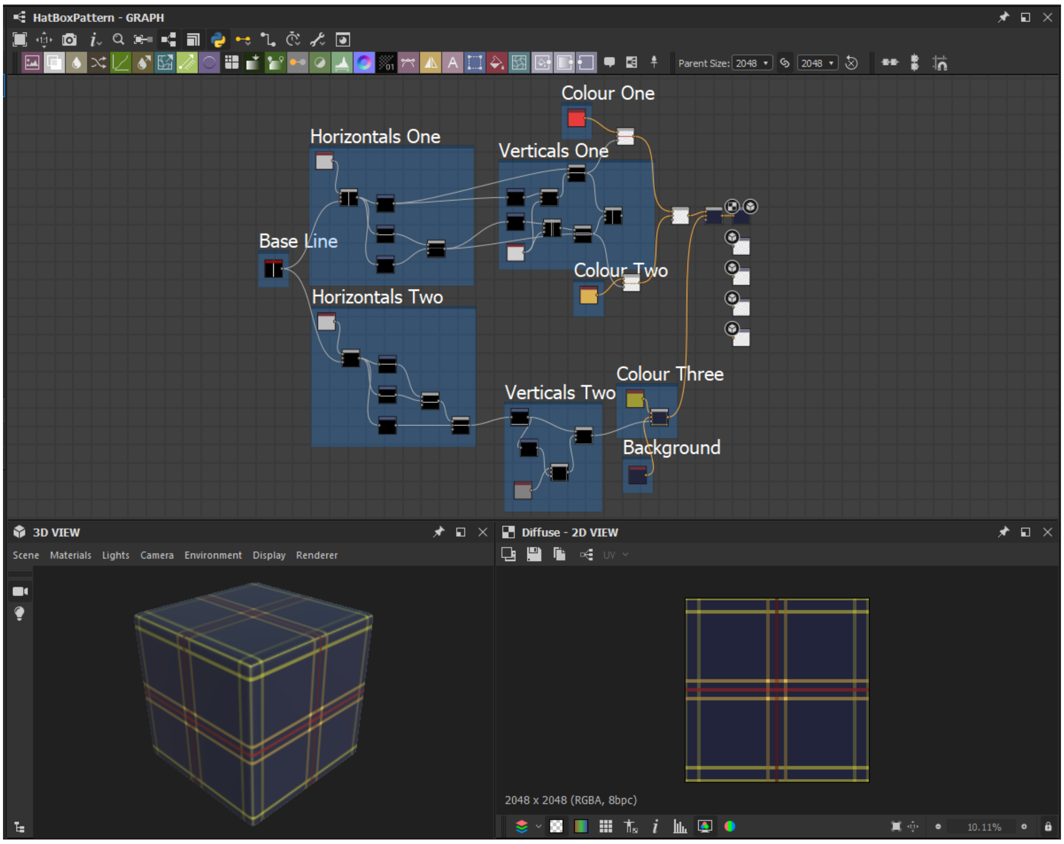
7.5.2.1.11.7 Asset Ten: Doll – Child

Began by creating a modified version of the Doll-Man rig with adjusted proportions to suit the sizes of the child doll. This was then taken into Marvelous to sim the outfit for him too, once more with the same concerns as the Doll Man:

The simulation came out rather elaborate and cleanup was required in Zbrush to make it look closer to the reference image. A re-topology was also required to give the character the correct polygonal density appropriate for usage within the HoloLens. Afterwards, the asset was unwrapped and textured in Substance painter:

7.5.2.1.12.7 Asset Eleven: Hat Box

The hat box proved to be somewhat of a frustrating asset to create as the main body of the box was constructed using fabric interwoven around a wooden/metal frame, however attempting to replicate this in 3D is difficult without a large among of sculpting and subsequently a higher-density polygonal mesh to maintain these forms. Within the interests of memory capacity and user performance, the decision was instead made to make the box a little more rigid which would have a less-imposing silhouette but a more consistent density and shape. Due to the nature of the pattern of the box, a custom material was required to texture it which was created using Substance Designer:



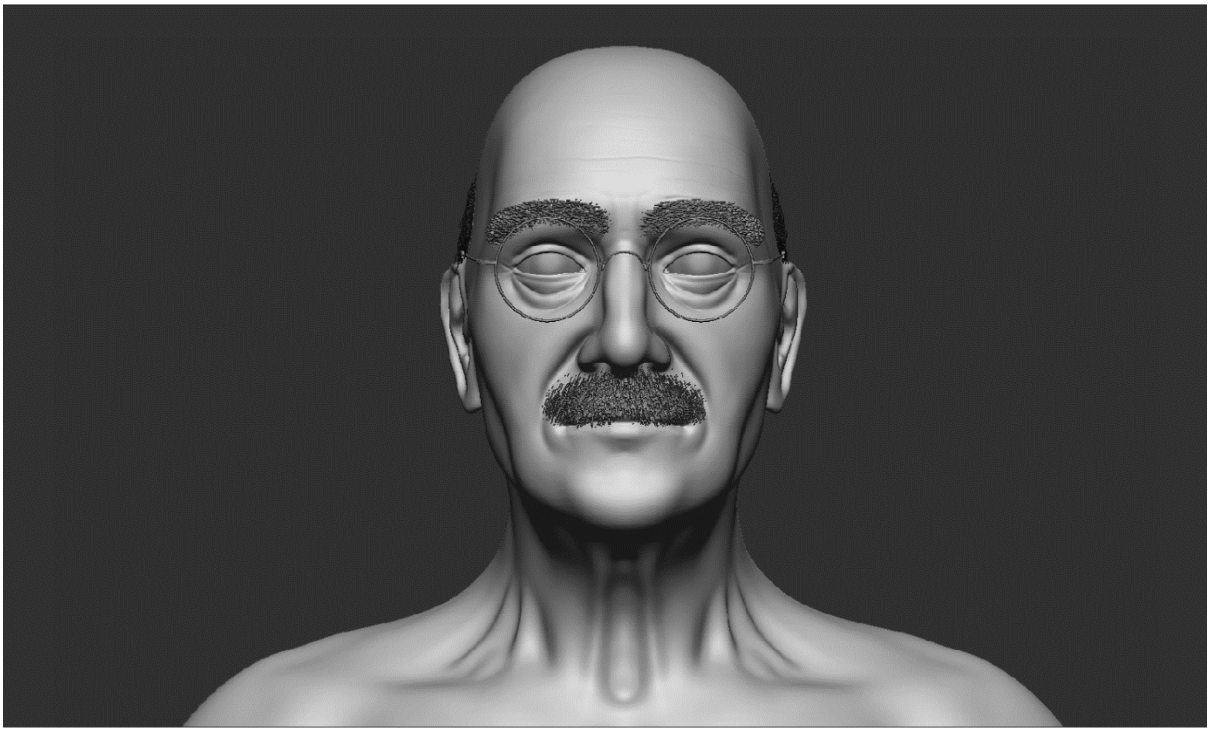
This was then used within Substance Painter (with some parameter adjustments) to texture the exterior of the box.

Whilst not visible from this image, the interior of the box has also been textured so that animation can later be possible and allow the user to open up the hat box for inspection.

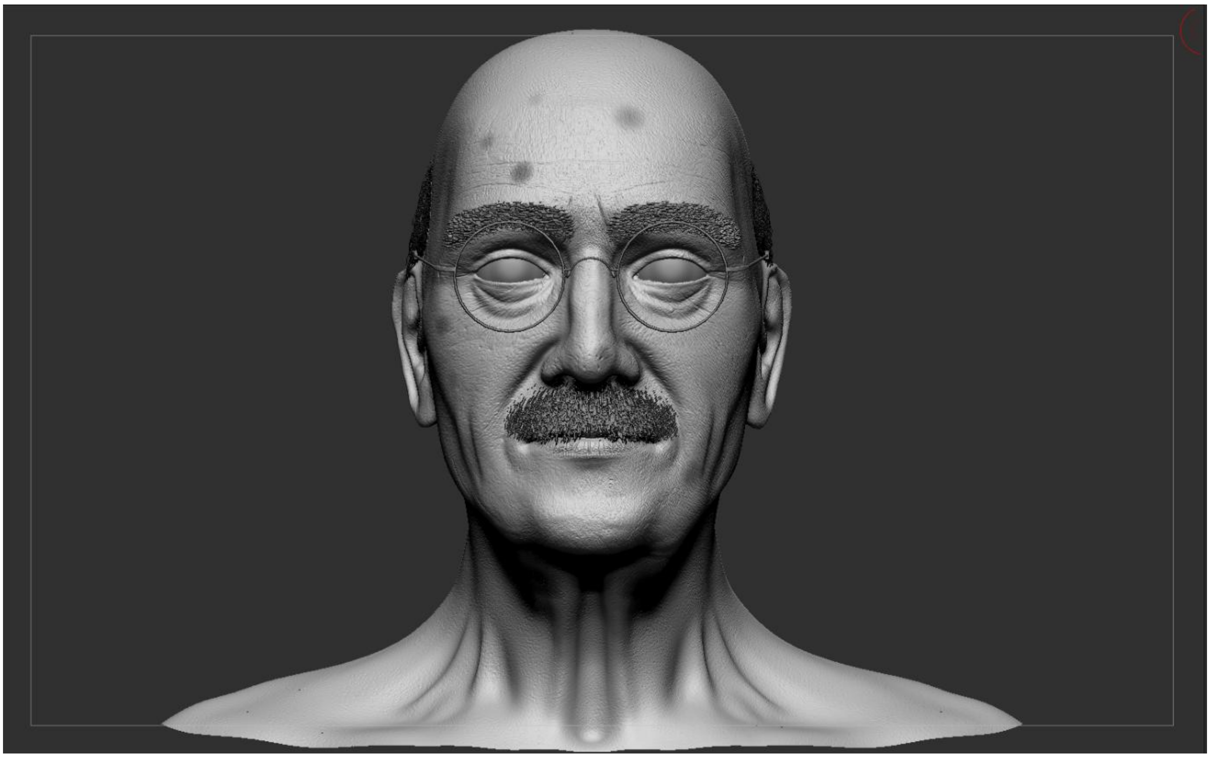
7.5.2.1.13.7 Asset Twelve: Gerald

(A full range of progress shots for Gerald can be found here: https://imgur.com/a/1L4FJ8X)

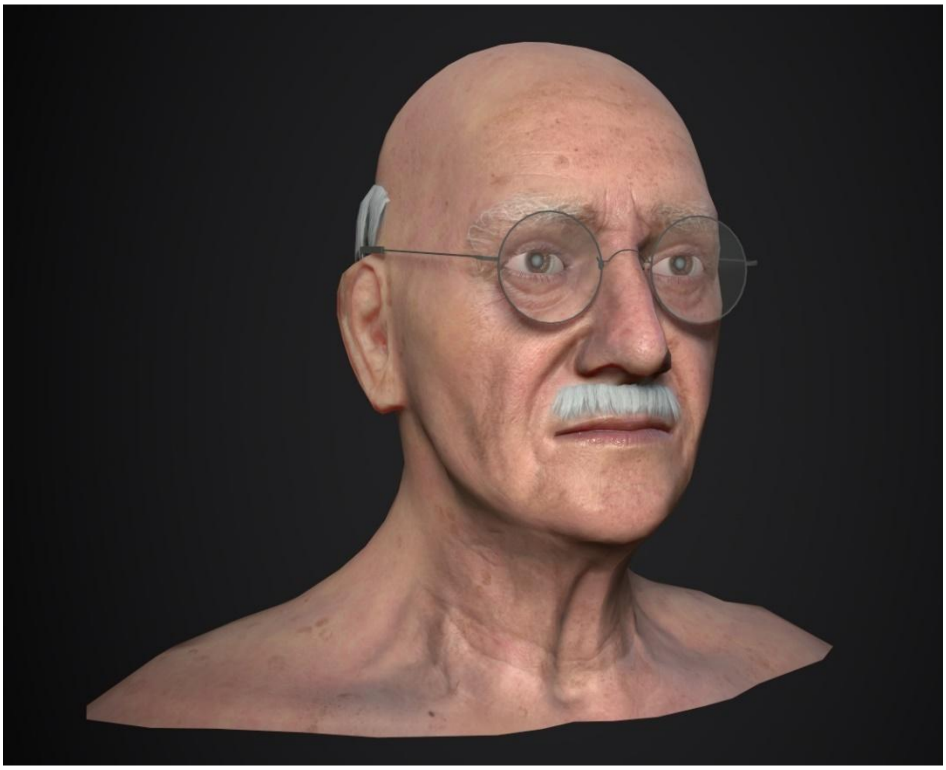
Due to the nature of the application, a character was required to act as both narrator and guide of the virtual learning experience. The original intention was to laser scan or photogrammetry one of the original Kindertransport survivors, however COVID-19 has made such an undertaking rather dangerous and could compromise the health of a vulnerable elderly person, so instead a custom character has been created from scratch. Inspiration was taken from photographs of the kindertransport survivors to create a generalised composite, however it is not a likeness of any of them (For ethical and legal reasons). This was the initially created sculpt:



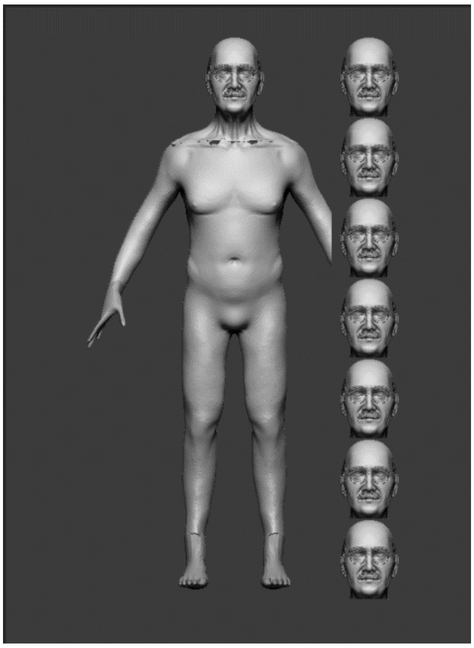
Displacement mapping data was used (purchased from TexturingXYZ) to create skin detailing information as this is the standardised industry workflow. As this data is taken from scans of real people, it is exceptionally accurate and incredibly detailed compared to hand-sculpting such surface data. Unfortunately TexturingXYZ has limited scan data and so the eldest male data I could acquire was that of a man in his 50s, which is unfortunately younger than Gerald is supposed to be. After creating the displacement and sculpting details over the top, this was the final result:



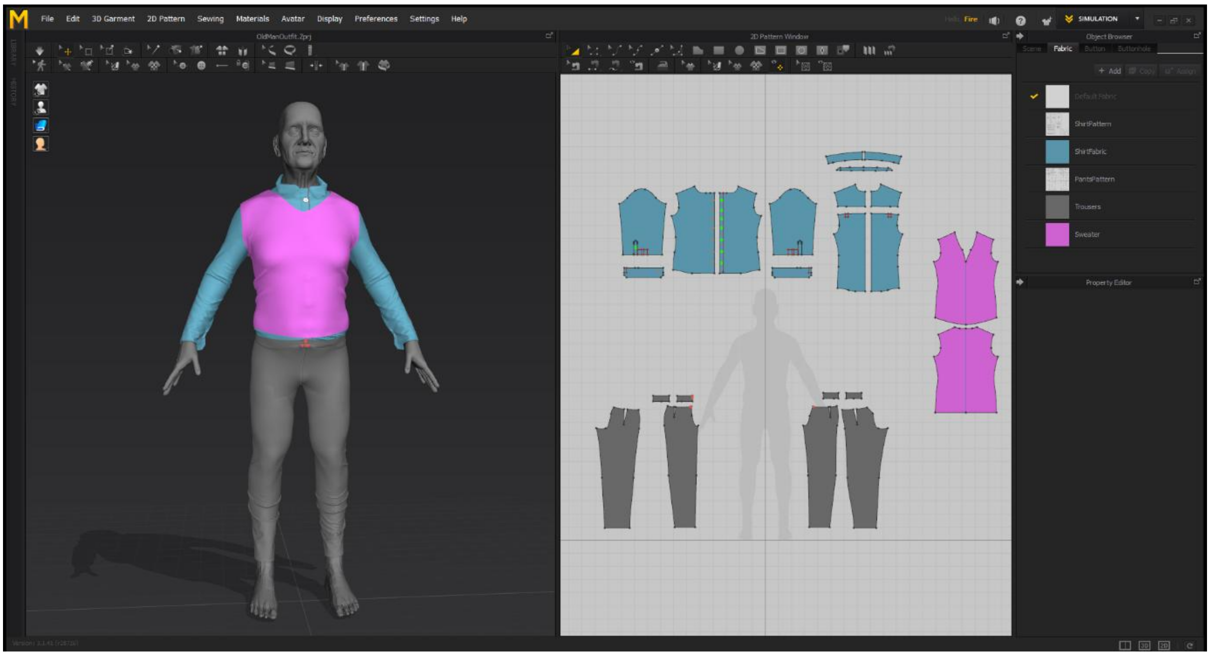
The head and hands required re-topologising and unwrapping, both of which were performed in Maya and texturing was done in a combination of MARI and Substance Painter. MARI was required to project skin data (also purchased from Texturing XYZ) onto the face, which was then blended with a manually created skin composite. The hair was created using Substance Designer to create variation in the strands. This was the result:



Because of the limited capacity of the HoloLens, creating a full body for use within the game was unnecessary; instead only a rough amalgamation of the underlying anatomical structured was needed to simulate over. This was massed out in Zbrush although mostly unrefined due to the time constraints and how perfecting the anatomy would ultimately be a fruitless effort as none of it would be seen beneath the attire. To give the character some personality, he was made to be overweight as a narrative element. His final height was a little under seven heads tall to prevent him from appearing as a heroic protagonist akin to superhero comics or the like.



His outfit was decided to be a shirt and trousers with a sweater-vest over the top as this was a recurring element in my investigation into the types of smart-casual clothing an elderly man might wear. This was then simulated in Marvelous Designer:

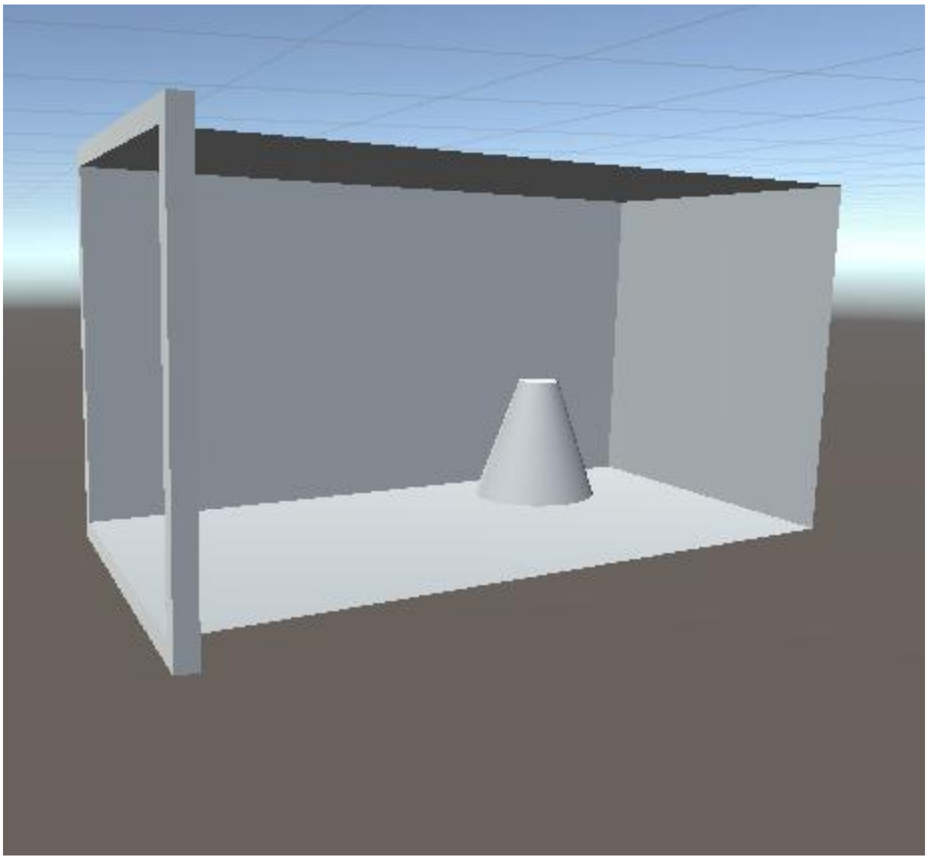


Materials were purchased from Substance Source as some complex texture detailing was required for his Sweater-vest, which still required substantial manual-adjustment to get working, and the trousers were re-simmed as the originals were too tight. Shoes and the tie were created using extracts within Zbrush and the belt was made purely from hand-painted heightmap data; no geometry was required. As another narrative element, fog was painted over his eyes to give the appearance of cataracts.

Gerald was then subsequently rigged via Mixamo and his body is ready for animation. A facial rig will be required to give facial animation.

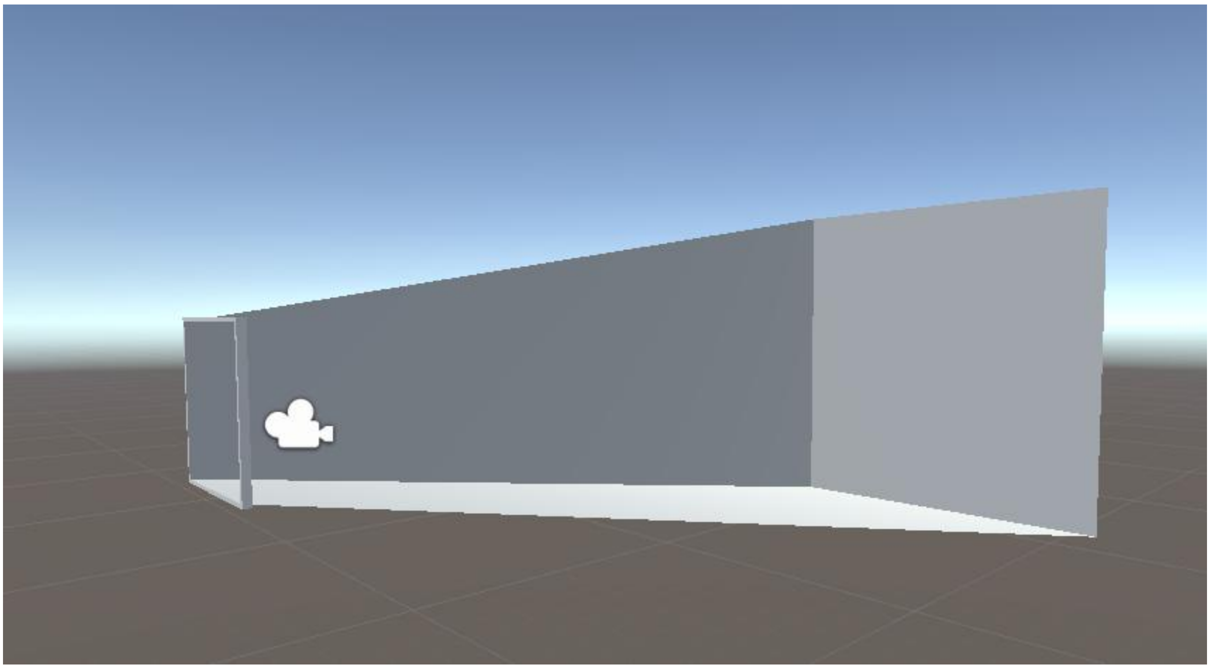
7.5.2.1.14.7 Asset Thirteen: Window frame

Detailing about the technical logistics can be found in the Programming section of this log. The window frame was originally created to emulate a vanishing point effect akin to those used in concept art to imply depth. Whilst this worked in theory, the reality was that such an effect did not translate well into a 3D effect as the shape of the geometry was too obvious. Originally the window geometry was shaped as such:



The cone was only to test for depth, the rest was shrunken inward slightly.

Upon implementing the geometry and fixing the scripts, a second attempt was made at the geometry to fix the depth effect. Rather than shrinking the end in to create a vanishing point, the opposite was instead attempted to create a full cone of vision for the player:



This newer effect was much longer and much broader than the original and creates a much more convincing illusion for the player. The cone effect underneath may need to be flattened out to create the illusion of the street being outside of the window.

7.5.2.1.8 Development log: Asset Functionality Designs

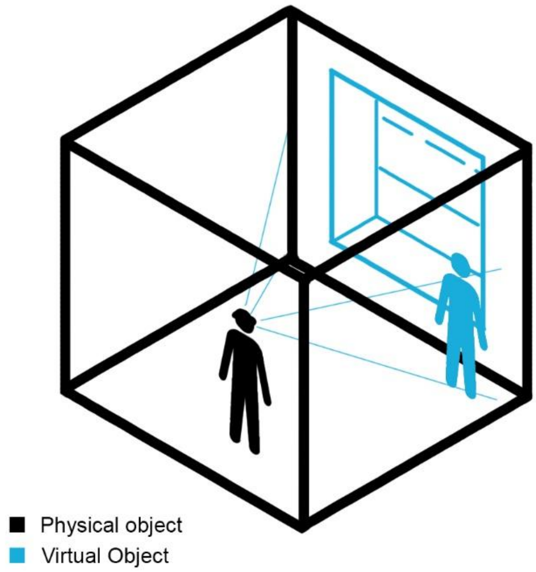
7.5.2.1.1.8 Asset One: Knaurs Konversations Lexikon book

The purpose of the book is somewhat limited as the logistics of virtualising the entire book are unfeasible for this project. The amount of memory space the asset would take up are far too substantial and so instead the readable area will be limited to a select few pages. To control the page flipping, the player will use a swiping finger gesture to imitate flicking pages.

7.5.2.1.2.8 Asset Two: The Window

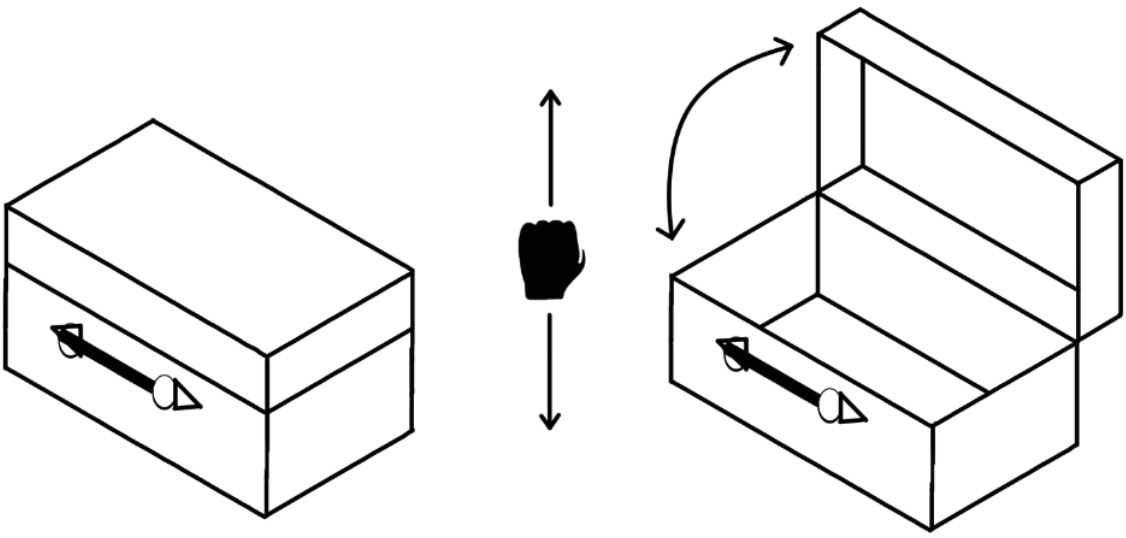
For more details on the window, please see the Window segment of the programming log.

The purpose of the window was to create a false sense of immersion within the shop, working to create a sense of belonging within the scene by emulating the exterior of the world through a virtual window. Whilst the technology of the HoloLens is not powerful enough to fully simulate an exterior environment, a fake window serves to provide a similar function without requiring as much graphical processing.



7.5.2.1.3.8 Asset Eight: Suitcase

Because the suitcase is a relatively simple prop, advanced functionality for it is an unlikely probability. At this time, the only realistic interactivity will be to either carry the case or to open it with a fist gesture, outlined as follows:



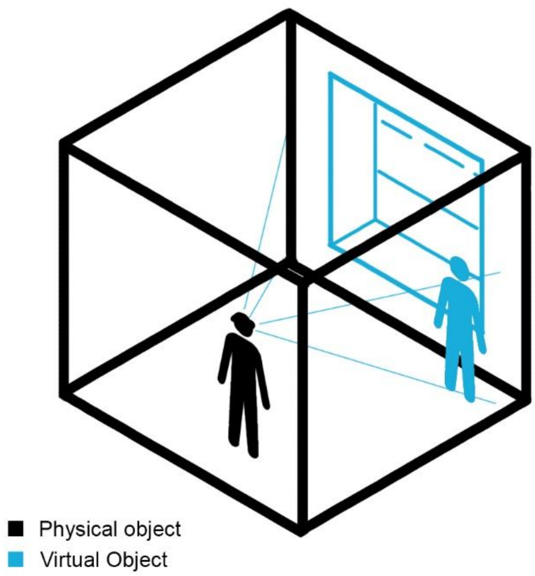
7.5.2.1.9 Development log: Programming

7.5.2.1.1.9 HoloLens

Following from the original prototype assembled for the early stage review, a new project was created with the name Echoes. The same principles were employed from before with the original setup, with assets imported in from Microsofts official tutorial content to establish a basic scene that was compliant with the camera, lighting, and backend scripting requirements of the HoloLens. Once these were established, development of the new build could begin. If this section seems prompt, it is because most of the technical challenge of getting the HoloLens to work was already dealt with last year and prior to this log being created. Although memory of these is now somewhat limited, most technical challenges initially revolved around getting the HoloLens emulator to function correctly. Although eventually resolved through assistance from Microsoft, the emulator proved to be a very inefficient way of testing builds due to its limited capabilities and lack of interactivity.

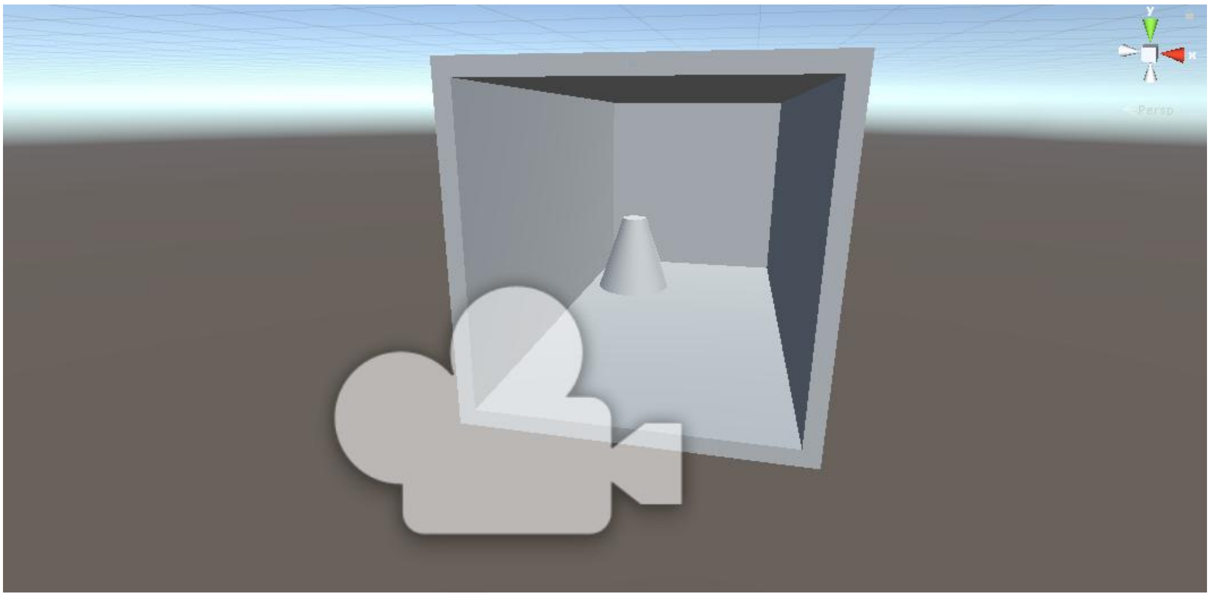
7.5.2.1.2.9 Window

A major challenge of the project is the virtual window. As depicted in the following diagram, the intention is to create a fake window that will be displayed over a physical wall.

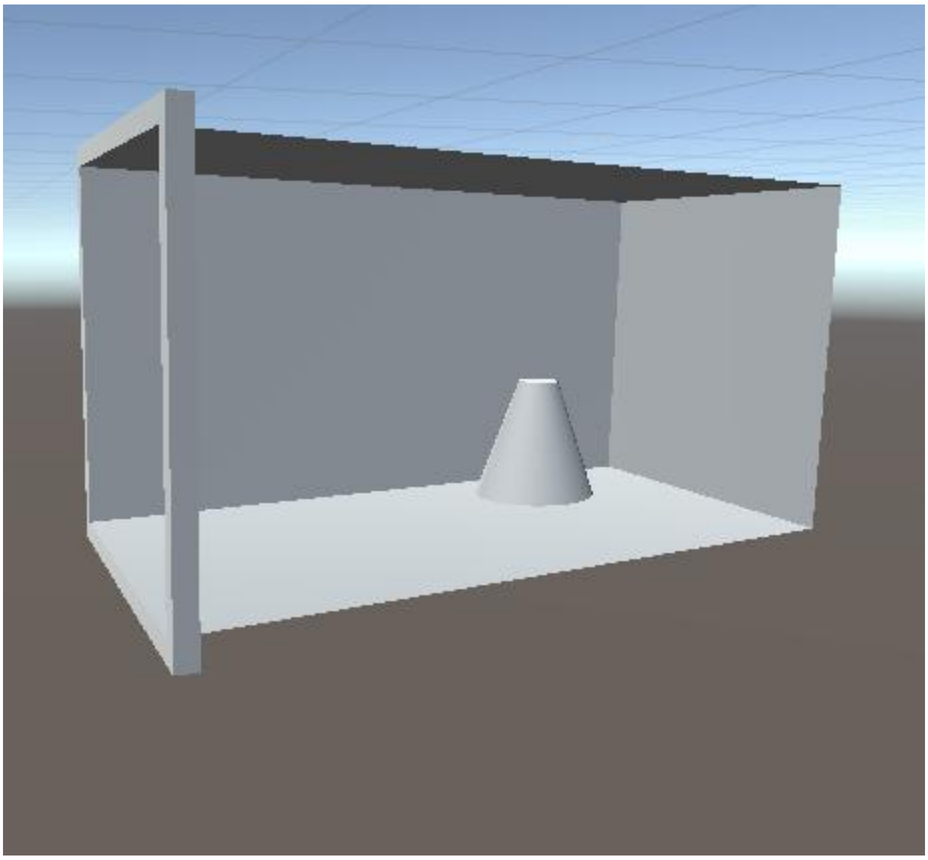


The virtual window requires a fake sense of depth and perspective to accurately convey a feeling that the user is looking out of a window. Simply projecting a texture onto the wall is insufficient as the image would be too consistent regardless of the users position in the real world.

To establish this, a test window was first created using some simple geometry consisting of an empty box and a single cone. The intention of this was to test the rendering and ensure that the concept would work.

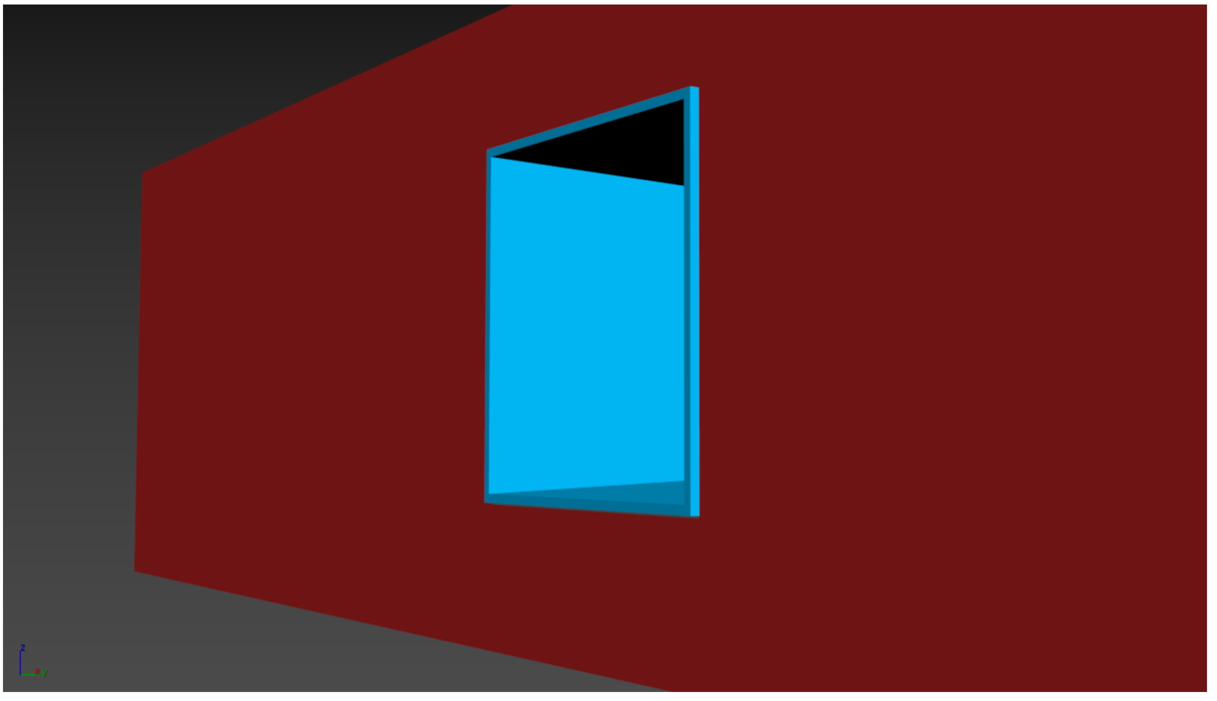


When standing before the window, the HoloLens rendered the geometry over the real world wall, meaning that it was possible for the user to look "out" of physical space and into a fake virtual one. This worked as intentioned, until looked at from the side. If the user stood away from the window and looked at it from any angle that wasn't directly in front of it, the depth geometry continued to be rendered regardless. This meant that the user could still see through the physical wall and out from angles where it should be physically impossible. For instance, if the user was standing to the side of the windowframe, they would see this:

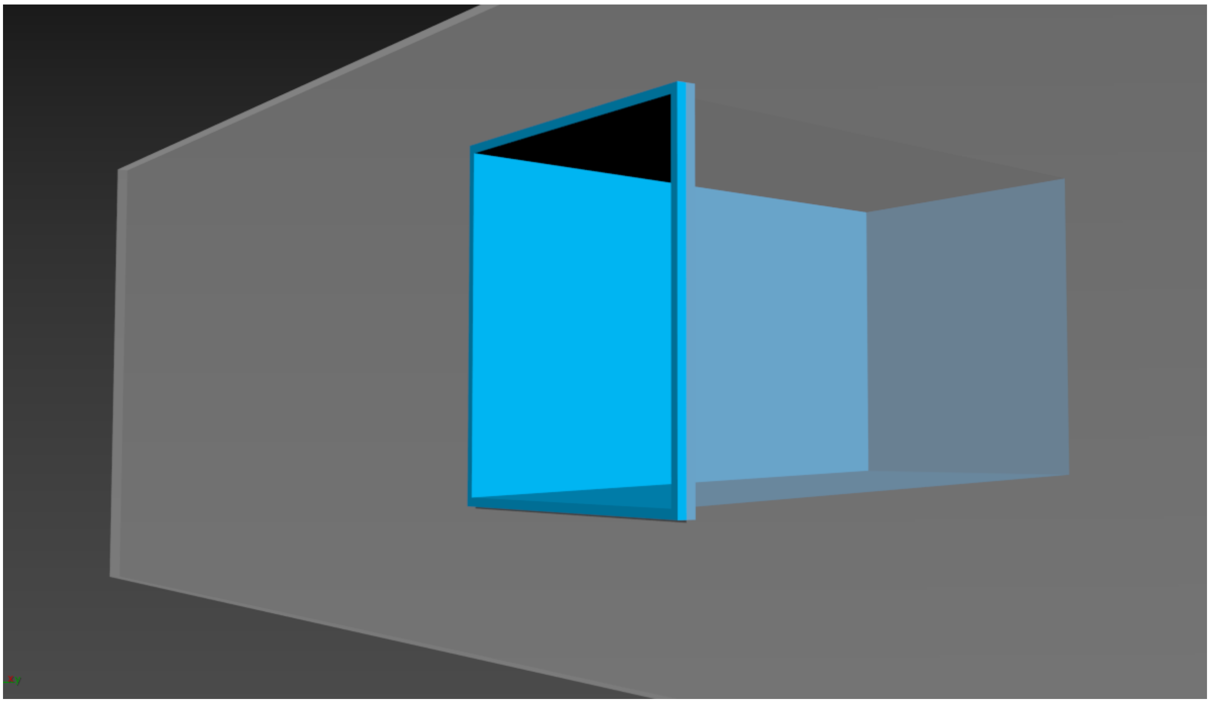


Logically the user should only be able to see the depth geometry when looking through the window frame and nowhere else, but this was not the case. Online research did not reveal any possible methods to cease rendering from alternative angles, meaning that the illusion would be destroyed as soon as they began moving around the room.

In the diagram below, the red wall represents the physical wall inside the museum and the blue window is what the virtual window theoretically *should* look like when looked at by the player.



However, the exterior of the window is **always** showing and looks similar to this:



This is problematic and if a solution cannot be found, the window idea will not be viable for the scene.

The alternative that was used was a render texture. Placing the real geometry far above the scene where the player cannot see it, the player instead looks through a fake window which is a flat plane inside of a frame. The player camera is scripted to synchronise with the render texture camera inside the window geometry. When the player looks around, the render texture camera mimics their movements identically, which in turn updates the render texture and creates the illusion of depth and perspective although it is not truly there.

Initially the second camera was parented to the first to match its movements. This proved to be a poor plan however, as the second camera pivoted around the main camera in all movements, meaning that small movements were pulling the camera too far from the window. A script would instead be required to control the second camera.

```
using Leap.Unity;
using System.Collections;
using System.Collections.Generic;
using UnityEngine;

Unity Script | 0 references
public class CameraSync : MonoBehaviour
{
    //Gets the main camera
    public GameObject camSync;

    private Vector3 offset;
    Unity Message | 0 references
    void Start()
    {
        //Calculates the distance between the cameras
        offset = this.transform.position - camSync.transform.position;
    }
    Unity Message | 0 references
    void LateUpdate()
    {
        //Matches the rotation of the main camera
        this.transform.rotation = camSync.transform.rotation;

        //Matches the movement of the main camera plus the offset
        this.transform.position = camSync.transform.position + offset;
    }

}
```

The original script created functioned mostly as intended by getting the main camera, calculating the offset between it and the window camera, then applying the movement (plus offset) and rotation to the window camera. The offset was important as without it, transform.position would snap the window camera to the location of the main camera. However, there was a problem with this script as the Z rotational axis was inverted on the window camera; when the player tilted their head left or right, the window camera rotated in the opposite direction. There did not appear to be a logical reason for this to occur, it simply did.

An update to the script was attempted to invert the Z axis. Instead of applying the direct rotation of the main camera, the script would multiple the Z axis direction by a value of negative one, which theoretically should invert it.

```
void LateUpdate()
{
    //Matches the rotation of the main camera
    Quaternion targetRotation = camSync.transform.rotation;
    this.transform.rotation = targetRotation * Quaternion.Euler(0, 0, -1);
```

Unfortunately, this did nothing. The logic dictated that it should work, but it did not.

After researching the matter online, an alternative was found still using quaternions.

```
void LateUpdate()
{
    //Matches the rotation of the main camera with the Z axis inverted
    var invertedRotation = new Quaternion(camSync.transform.rotation.x, camSync.transform.rotation.y, -camSync.transform.rotation.z, camSync.transform.rotation.w);
    this.transform.rotation = invertedRotation;
```

Now instead of attempting to multiply a single axis by a value of negative one, the rotation would instead directly invert the Z axis and apply that to the scene camera.

Upon testing, it became apparent that whilst functional, this was a remarkably silly thing to do. So much effort went into finding a solution to the Z axis rotation that a very simple concept was forgotten: the Z axis should not rotate with the player. With it implemented, the entire outside world rotated whenever the player tilted their head. This not only looked ridiculous but also shattered any hopes of immersion. Instead of inverting the Z axis, the script was changed to give the Z rotation a flat value of 0 to ensure that it would never rotate.

```
//Matches the rotation of the main camera with the Z axis inverted
var invertedRotation = new Quaternion(camSync.transform.rotation.x, camSync.transform.rotation.y, 0, camSync.transform.rotation.w);
this.transform.rotation = invertedRotation;
```

This result is much more consistent with the real world and allows the depth effect to function as intended.

7.5.2.1.3.9 Leap motion

The leap motion controller is proving frustratingly difficult to configure. The drivers have been installed from the website but it still won't recognise my sensor. Every time I open the control panel it claims that the leap motion service is inactive. I cannot get it to recognise the sensor at all.

Update: For reasons unknown the control service in my task manager automatically disabled the leap motion controller. This has been fixed and it is now functional.

Error: The visualiser won't recognise my hands. I can see them in the camera but nothing is happening regardless of what I do.

Update: The control panel for the leap motion does not automatically install the drivers for the sensor. They have to be found in the install directory and installed manually. The device now recognises my hands.

I have installed the Unity SDK for the Leapmotion and opened the sample build.

Error: My hands are not recognised. Unity won't acknowledge my hands even though the sensor control panel is. I'm going to post on the unity forum to ask for assistance.

Update: I found a forum thread with the same problem, since the latest update the leap motion kit for unity only works if you install the VR variant. The tabletop version is confirmed to be bugged. For now I will have to work with the VR version.

Update: Unity is now recognising my hands. I have created a little scene with a rigid body sphere that can be picked up and thrown around! This is actually quite fun.

Error: I cannot work out how to use hand gestures. There is almost no documentation for this thing.

Update: I have found documentation online.

Error: I still cannot get the gestures working regardless of what I do. The code seems to be simple enough but when I try to set it up, I get met with errors about the code being obsolete? I'm working with the latest version so I don't understand.

Update: I was asking in the Unity discord channel and got to meet another Leap motion developer called Cait who has informed me that the gesture functionality was removed from the Unity SDK after version 2, we are currently on version 4. It is not possible to use hand gestures anymore and I don't know how to proceed from here.

Update: I found a plugin on the Unity store that restores hand gestures to the leap motion. It cost £20 but so far it has been worth it. The only problem is that it did not include any documentation so I'm going to have to reverse engineer one of the sample scenes to get it working.

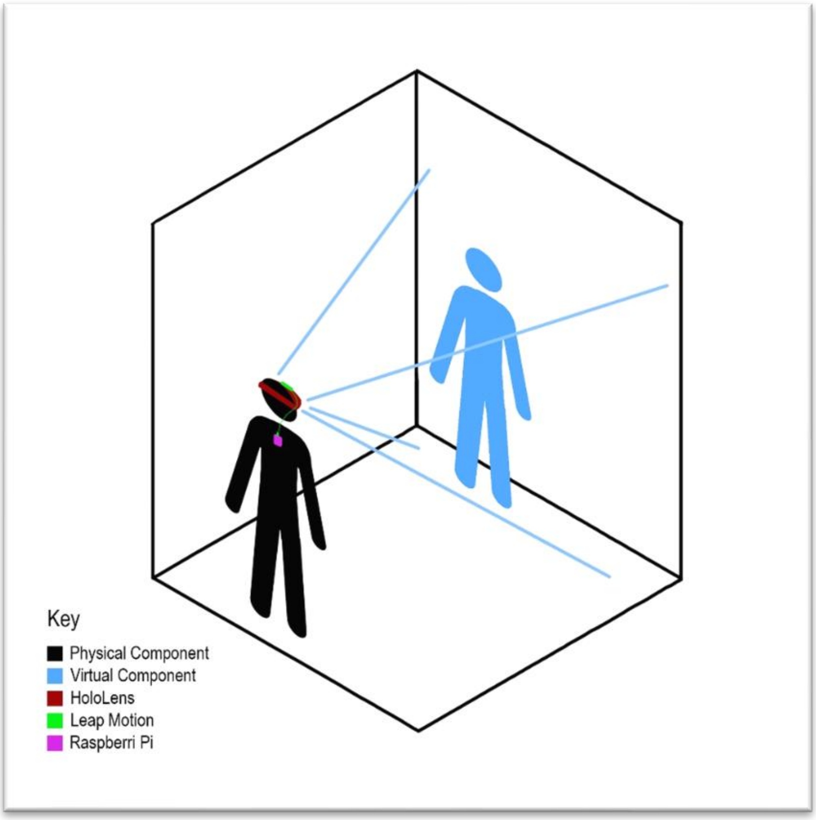
Update: I have achieved a basic gesture. By swiping left with my right hand, I can make a cube change colour. Progress!

Update: I have now imported the book into Unity and enabled animation controls with swipe gestures. It's working!

Error: The gesture controllers will all trigger simultaneously. If more than one object is triggered by a swipe gesture, every action will fire off at the same time. Would a vision based detection system work?

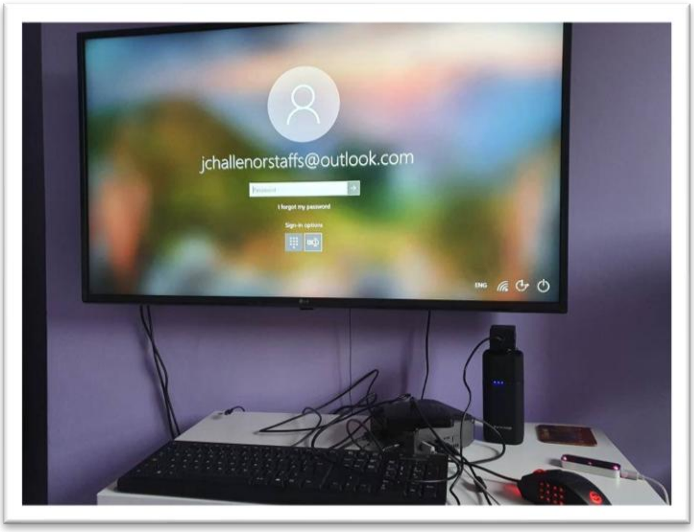
7.5.2.1.4.9 Networking

The original design for the networked devices was as follows:



As the Leap Motion cannot physically connect to the HoloLens via cables nor connect to it via Bluetooth, an intermediary device was required to parse the inputs to the HoloLens. The theory was that a raspberry pi would be capable of performing this task due to their versatility and reputation for being able to perform a significant number of technical tasks, providing they are sufficiently programmed to do so. A Raspberry Pi 4 was purchased for this task and set up, however it proved unable to perform its intended task; the Raspberry Pi operates using an ARM processor rather than an X86/64, which proved problematic as the drivers for the Leap Motion are incompatible with ARM processors. As such it had to be returned and replaced with a ACEPC AK2 Mini PC, a device which runs Windows 10 and has an X86 type processor which made it capable of running the drivers for the Leap Motion.

Following this, another complication arose as to how to power the MiniPC. The device was built to be plugged into an AC outlet, but the project requires the user to be fully mobile and consequently they cannot be tethered to a wall. An Anker battery bank was implemented to power the MiniPC but did not work. This is pure speculation, but it is likely that a USB port was unable to consistently output enough power to keep the machine active, as the MiniPC would immediately turn off after booting. Investigation was done into power outlets and the only battery bank that had an AC outlet port was a Ravpower battery bank. One was purchased and it worked; the battery was able to sufficiently power the MiniPC.



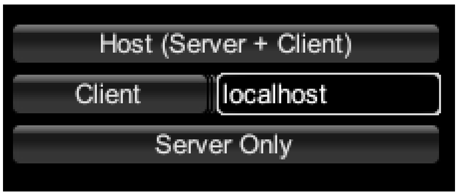
This resolved the issue of hardware but did not provide a solution to how to parse the inputs between devices. Investigation was performed into using Parsec to transfer inputs, as this software allows for networked inputs from devices that are interpreted locally on the host machine. Unfortunately, this did not work because Parsec was incompatible with the LeapMotion, it appears that it only works with keyboards or game controllers at this time.

The next attempt was to implement networking controls within Unity itself. Instead of attempting to transmit the raw inputs from one device to another, instead a Local Area Network build of the unity project would be deployed to both devices and virtual manipulatives would be controlled entirely through their respective devices, however the outcomes would be synchronised.

Initial attempts at this were attempted via Unet but this was quickly abandoned because Unet has since been deprecated and is no longer supported by Unity. Instead an alternative called Mirror was used, which is a community-built successor to Unet and functions in mostly similar fashions. Mirror comes with remarkably few tutorials or resources as one of the lead developers on the project creates paid tutorial content for using it. This made implementing Mirror a more difficult affair than it had any right to be but thankfully was managed with help from the Mirror discord community.

The first challenge was to establish the basic network and allow two devices to connect. Initial experimentation was done with the MiniPC and the HoloLens but this was abandoned after the first few days because it was taking far too much time to deploy builds to both devices. Instead testing was done with a desktop PC and a laptop, both connected to the same network. Early experimentation managed to get the two devices to connect after significant difficulties finding the host, as Unity needed to be allowed through the firewall and running the build as an administrator turned out to be mandatory for letting the devices discover each other. After this, a basic script was placed onto a cube to allow it to be moved by pressing the spacebar, and this is where the main trouble began. Pressing the spacebar would make the cube move, but it only synchronised from the server to the client and not vice-versa. This meant that all leap motion inputs would have to be done on the server and have the HoloLens synchronise them, which worked but still left the problem that the HoloLens may need to synchronise its own inputs to the MiniPC and would not be able to.

Using the HoloLens to connect to the server proved to be impossible. Mirror uses an old Unity user-interface setup to create buttons at runtime and the user clicks which button corresponds to their situation; whether they wish to be a host, a server or if they want to connect to an IP address as a client.



Because of this, it was impossible to actually select anything from the HoloLens itself. Because the UI was bound to the camera and the camera was bound to the players head, there was no way of selecting any button options. Instead, a custom version of the Network Manager HUD script had to be made which differed slightly from the original. The custom version was given an Awake function to automatically detect which platform it was running on; if it was anything other than a Windows player (or the unity editor) it would automatically connect to the IP address of the server. This allowed the build to run on the HoloLens as now it would automatically connect. However, as there is no way of changing the server IP address inside the HoloLens, the server device was changed to have a Static IP address. This will have to be done at the Museum too on the MiniPC or else this project will not work, but there is unlikely an alternative solution.

```
void Awake()
{
    manager = GetComponent<NetworkManager>();
    if (Application.platform == RuntimePlatform.WindowsPlayer)
    {
        manager.StartHost();
    }
    else
    {
        manager.networkAddress = "192.168.0.107";
        manager.StartClient();
         //showGUI = false;
    }
}
```

Following this the leap motion was again implemented on the server machine to attempt to control the same cube using the leap motion controls, bound to a fist gesture. This functioned as intentioned, with the user able to control the cube by making a fist and moving their hand around. When tested with the MiniPC and the HoloLens, it also functioned properly and allowed the user to control the manipulative using their hand.

The next problem arose that the old man character in the scene no longer animated at all. Previously he was able to stand around idly and would wave back if waved at, however all animations had since ceased. Problematic though this was, investigation revealed that this was due to the implementation of Mirror. As the build was now networked rather than ran locally, the animator component required configuring as a networked animator instead of a regular one. After making the conversion, the animations worked once again.

Upon testing the build from the HoloLens and the desktop PC as the server host, a problem arose that the camera in the scene was un-synchronised. This was a problem because of the orientation of the player; although the player could move around their scene, the camera position would never update to the server meaning that the server was unaware of the players new orientation. Because of this the leap motion controls would become inverted if the player performed a 180 degree rotation.

Investigating this issue opened a large metaphorical can of worms because Mirror requires an authority system to be implemented within its functionality to determine if an object can be manipulated by the server host or a client. Unfortunately, there is no simple way of configuring authority; no component exists nor is there a tick box or any other rational solution. Instead authority would have to be manually assigned using code, which is no small feat.

By default the server will automatically assume authority of any networked object. Mirror is configured with a very common understanding of game engine networking in that each client will spawn a player character upon connecting and authority will be granted to the client at the point of instantiation. Because this project is rather bespoke in nature, using a player character would not be an appropriate means of configuring the scene as the spatial mapping requires every object to be placed in its correct location prior to the build being ran. Regardless, a similar idea was used to instead record the required world space/rotation values of every object and spawn all the scene objects at runtime in their correct locations, which allowed for authority transfer to occur immediately. Performing this method involved using Mirror Commands; a type of function that has to be called from the client to the server and are incredibly difficult to setup because of the number of arguments and parameters required for them to work. This succeeded in populating the scene and establishing authority but broke the Leap Motion controls. The Leap Motion control system requires each manipulation to be pre-determined in the scene before runtime which meant that spawning objects in after initialising would not work.

```csharp
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using Mirror;
//using NUnit.Framework;

public class PlayerScript : NetworkBehaviour
{

    //Assigns starting location
    public Vector3 Position = new Vector3(0, 0, 0);
    public Vector3 Rotation = new Vector3(0, 0, 0);

    NetworkManager networkmanager
        ;
    void Start()
    {
        //gets the Network Manager
        networkmanager = FindObjectOfType<NetworkManager>();

        //Spawns the moveable cube on the server
        int index = 1;
        if (GetComponent<NetworkIdentity>().hasAuthority)
        {
            CmdSpawnObjectToMove(index, gameObject, Position, Rotation);
        }
    }

    [Command]
    void CmdSpawnObjectToMove(int index, GameObject localClient, Vector3 position, Vector3 rotation)
    {
        //Gets the cube prefab, spawns it at the correct location/rotation and assigns authority to the local client
        GameObject objToSpawn = Instantiate(networkmanager.spawnPrefabs[index], position, Quaternion.Euler(rotation));
        NetworkServer.Spawn(networkmanager.spawnPrefabs[index], localClient);
        RpcMoveSpawnedGoToSpawnLocation(position, rotation, objToSpawn);

        //Checks to see if the build is running as a client or server. If it's a server, revoke authority. If it's a client, grant it.
        if (isServer)
        {
            objToSpawn.GetComponent<NetworkIdentity>().RemoveClientAuthority();
        }

        if (isClientOnly)
        {
            objToSpawn.GetComponent<NetworkIdentity>().AssignClientAuthority(connectionToClient);
        }

    }

    [ClientRpc]
    void RpcMoveSpawnedGoToSpawnLocation(Vector3 position, Vector3 rotation, GameObject spawnedObj)
    {
        spawnedObj.transform.position = position;
        spawnedObj.transform.rotation = Quaternion.Euler(rotation);
    }
}
```

Instead of relying on instantiating each object with the correct authority, instead experimentation began to see how to correctly transfer authority from an object that already exists within the scene. The concept was simple; locate the correct object, determine who had authority over it and if it was the server, revoke authority and grant it to the client. Once more this proved a little fiddly due to how commands must be structured but did prove to work. This method, whilst functional, was unfortunately not appropriate for the project as it did not scale beyond a single object. It was possible to add more objects in, but each would have to be hard-coded and include exceptionally more lines of code, which would be inefficient.

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using Mirror;

public class AuthorityClaimer : NetworkBehaviour
{
    GameObject ObjectToMove;
    private void Start()
    {

        //Finds the object to be moved

        ObjectToMove = FindObjectOfType<ObjectMoveNoN>().gameObject;

        //The server relinquishes authority
        if (isServer)
        {
            CmdRemoveAuthority(ObjectToMove);
        }

        //The client takes authority
        if (GetComponent<NetworkIdentity>().hasAuthority && !isServer)
        {
            CmdAssignAuthority(gameObject, ObjectToMove);
        }
    }
    [Command]
    void CmdAssignAuthority(GameObject obj, GameObject objectToMove)
    {

        objectToMove.GetComponent<NetworkIdentity>().AssignClientAuthority(obj.GetComponent<NetworkIdentity>().connectionToClient);
    }

    [Command]
    void CmdRemoveAuthority(GameObject objectToMove)
    {
        objectToMove.GetComponent<NetworkIdentity>().RemoveClientAuthority();
    }
}
```

The next experiment was designed with efficiency in mind; instead of hard-coding in each object, instead an array should be constructed that would be accessible inside the editor and allow for objects to be added and removed from it as required without having to adjust the code. The code would go through each object in the array and grant authority to the client as soon as they connected to the server, therefore establishing the necessary control each time it was needed. This script took some time to create and much assistance was needed from the Mirror Discord community to work out the correct structure for the array and loop. Credit is given to the Discord community users Goesm#0299 and NinjaKickja#6118, without whom this would not have worked. After many iterations of errors, code changes and problems, the method finally worked. This was the method that will be used in the project as it functions as intended and allows for limitless upscaling without having to make further edits to the code.

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using Mirror;

Unity Script | 0 references
public class SceneAuthorityClaimer : NetworkBehaviour
{
    26 references
    public override void OnStartServer()
    {
        //Prints that the server is functioning
        print("OnServerStart being called");

    }
    7 references
    public override void OnStartLocalPlayer()
    {
        //Only runs the command to retrieve authority if the user is a client, not a host
        if(isClientOnly)
        {
            CmdAssignAuthority();
        }
    }
    [Command]
    1 reference
    void CmdAssignAuthority()
    {
        //Gets the Scene object authoriser
        GameObject Authoriser = GameObject.Find("SceneObjectAuthoriser");

        //Goes through the auth array and assigns client authority to all objects in the array
        var authArray = Authoriser.GetComponent<AuthArray>();
        for (int i = 0; i < authArray.clientObjects.Length; i++)
        {
            authArray.clientObjects[i].GetComponent<NetworkIdentity>().AssignClientAuthority(GetComponent<NetworkIdentity>().connectionToClient);
            print("ObjectAuthorised");
        }
    }
}
```

7.5.2.1.9.1.4 Object Parenting

Part of this project involves the player being able to pick up objects and hand them to Gerald. Gerald must be able to take the object, hold it in his hand, play a talking animation and play the correct sound file, then place the object back down when he is finished. To achieve this, a quick mock-up was built in a blank project to minimise potential disruptions of the main project. The concept was simple, upon pressing the spacebar, a sphere would be made the child object of a blank game object that was a child of Gerald's hand. This was the script to do so:

```
Unity Script | 0 references
public class SocketScript : MonoBehaviour
{
    //Gets the sphere and the hand-socket
    [SerializeField] public GameObject sphereSock;
    [SerializeField] public Transform parentObj;


    // Update is called once per frame
    Unity Message | 0 references
    void Update()
    {
        //Socket the sphere to the hand upon pressing the spacebar
        if (Input.GetKeyDown("space"))
        {
            SocketIt();
        }
    }

    1 reference
    void SocketIt()
    {
        //Print a message to confirm the command was received
        print("space key was pressed");

        //Set the hand as the parent
        sphereSock.transform.SetParent(parentObj);

    }
}
```

This was successful in turning the sphere into a child object, however it did not work quite as intended as the sphere remained in its previous location rather than being centred to the palm of Gerald's hand. To adjust this, a new line was added after childing the object to set its local position to 0,0,0, meaning that it would be in Geralds hand.

```
Unity Script | 0 references
public class SocketScript : MonoBehaviour
{
    //Gets the sphere and the hand-socket
    [SerializeField] public GameObject sphereSock;
    [SerializeField] public Transform parentObj;


    // Update is called once per frame
    Unity Message | 0 references
    void Update()
    {
        //Socket the sphere to the hand upon pressing the spacebar
        if (Input.GetKeyDown("space"))
        {
            SocketIt();
        }
    }

    1 reference
    void SocketIt()
    {
        //Print a message to confirm the command was received
        print("space key was pressed");

        //Set the hand as the parent
        sphereSock.transform.SetParent(parentObj);
        sphereSock.transform.localPosition = new Vector3(0, 0, 0);

    }
}
```

This was successful and allowed for an object to be given to Gerald. The next step in the process was to change the trigger for Gerald to take objects from a button press to collision as the players leap control inputs would have them physically handing an object to him. The palm socket and the sphere were given collision triggers, along with the sphere being given a set of basic controls to allow for it to be moved around in the debug environment. The trigger to instigate the parenting process was adjusted to be OnTriggerEnter.

```
void Update()
{
    //All following If statements handle controls
    if (Input.GetKeyDown("space"))
    {
        SocketIt();
    }

    if (Input.GetKey("w"))
    {
        this.transform.Translate(Vector3.up * Time.deltaTime);
    }

    if (Input.GetKey("s"))
    {
        this.transform.Translate(Vector3.down * Time.deltaTime);
    }

    if (Input.GetKey("a"))
    {
        this.transform.Translate(Vector3.left * Time.deltaTime);
    }

    if (Input.GetKey("d"))
    {
        this.transform.Translate(Vector3.right * Time.deltaTime);
    }
}

Unity Message | 0 references
public void OnTriggerEnter (Collider other)
{
    // Socket the sphere on trigger enter
    SocketIt();
}
```

This too worked, although the sphere required a rigid body component before the trigger would work. With this functional, the next step in the process was to script the process of Gerald animating and playing a sound file upon being given an object. For the purposes of building this functionality in an otherwise empty build, a quick animation was created in the Unity animation editor of Gerald moving from left to right, and a royalty free music track was used for the sound file. Furthermore, another void was created to be invoked after a five second delay to stop the animation/soundfile purely for the purposes of development, but this will not be needed for the final build. After both are finished, Gerald will then put down the object he is holding and it will de-parent from him.

```
void SocketIt()
{
    //Print a line to acknowledge
    print("Socketed to hand");

    //Hand is now the parent object of the sphere
    sphereSockCol.transform.SetParent(parentObjCol);

    //Local position is set to 0,0,0 so it's centered to his hand
    sphereSockCol.transform.localPosition = new Vector3(0, 0, 0);

    //Play the song and animation
    geraldAudioS.Play();
    sphereAnim.SetBool("hasSphere", true);
    print("Getting jiggy");

    //Stops the animation and song after 5 seconds
    Invoke("StopAnim", 5);
}

0 references
void StopAnim()
{
    //Stops animation and song
    geraldAudioS.Stop();
    sphereAnim.SetBool("hasSphere", false);
    print("No Longer jiggy");

    Invoke("UnSocketIt", 1);
}

0 references
void UnSocketIt()
{
    //Puts down the object whne done
    sphereSockCol.transform.parent = null;
    sphereSockCol.transform.localPosition = new Vector3(-1, 0, 0);
}
```

This all worked as intended. The next step was to adjust the script to make it scaleable. Gerald currently has an animation controller that can be controlled via use of Boolean variables, but there is no current way to specify which sound file he plays upon receiving an object. If he is given any object, he will always play the sphere sound file.

To fix this problem, each sound clip is now referenced by the individual object, and will be played upon pickup from an audio source located on Gerald himself. This allows for multiple objects to exist that can all trigger their own required animations and sound files.

```
//Play the song and animation
geraldAudioS.clip = sphereClip;
geraldAudioS.Play();
sphereAnim.SetBool("hasSphere", true);
print("Getting jiggy");
```

Gerald was then tested using two objects; a sphere and a cube. Each had their own sound file and animation. He should be able to hold each object, play a different sound file and animation, then put them back down again. This test was successful and a video of it can be found here: https://youtu.be/wtuwA4dTv8E .

With the script functional, the next step was to bring it into the main build. The difficulty with this concept lays within the networking functionality; the object needs to be visibly paired on both client and server. Initially the basic script from before was used with the intention of parenting a sphere to Geralds hand with a network transform component on it. The idea was that due to the network transform component, the sphere would move on the client application too even though it would only be parented on the server, however the client user would be oblivious to this. Unfortunately this did not work due to a rather interesting reason.

Upon being parented, the sphere sets its local position to 0,0,0 to make itself be attached to Geralds hand. On the server this was fine and all worked as intended. On the client, the application was unaware that the object had been parented and so when the script was executed to set its position to 0,0,0, it did so to world space position 0,0,0. This is an interesting quirk but a solution needs to be found to either parent the object on both devices, or find an alternative method.

7.6. Appendix 6: Timeline of Project

The following table includes the timeline of the project with all major developments and stages. The timeline of the project was severely impacted due to the Covid-19 Quarantine, which slowed development of the project along with preventing testing from being performed due to the restrictions imposed. Furthermore, development was again later slowed due to employment and transitioning from full-time to part-time study.

Time Period	Project Phase	Key Activities	Outputs/Milestones
October 2018 – May 2019	Project Initiation (Original Concept)	Initial literature review, creation of first prototype, exploration of potential research questions, visit to Neuengamme Concentration Camp.	Unreal Engine 4 AR Prototype. Initial draft of ethical approval. Written version of review of literature for publication (Peer reviewed).
June 2019 – October 2019	Early Stage Adjustment	Change of project design/research partner. New prototyping for narrative based AR experience. Visit to National Holocaust Centre & Museum. Early Stage Review.	Unity Engine AR prototype. Amended ethics documentation for new design. Early Stage Review completion.
November 2019 – March 2020.	Design rescope	Adjustment to updated design (Moving away from narrative to educational experience), development of assets.	Updated ethics documentation, 3d assets for project.
March 2020 – September 2021	Slowed development due to Covid-19 quarantine	Continual development of 3d assets. Development of Unity project. Voice acting commissioned. Late Stage Review. Writing of publication for output.	Completed development of both versions of the application (Mobile and HMD). Paper submitted for publication (Publication accepted, but publication was delayed due to the pandemic).

October 2021 – January 2023	Transition to Part-Time Study & Testing	Transition from full-time to part-time study due to employment. Approval of ethics application. Completion of testing and data collection.	Ethical approval gained. All four tests completed. Both points of data collection completed.
February 2023 – May 2023	Writing of publication for output	Writing a paper on the findings of the testing for publication.	Publication on the findings of the research (peer reviewed).
June 2023 – January 2025	Writing	Writing of thesis	Thesis written and submitted.
August 2025	Viva	PhD Viva	Thesis accepted with minor corrections.
September 2025 – February 2026	Writing corrections	Corrections written Paper written for publication.	Thesis re-submitted with corrections. Paper submitted for publication on next research project (peer reviewed).

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