Virtual Reality Learning Environment with Focus on Usability and Multimodality

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Abstract

As virtual reality technology becomes more available in educational settings, greater work and research goes into designing and creating virtual reality learning environments (VRLEs). Current literature suggests that there is a lack of focus on multimodality and usability in the design and implementation of these environments. Using a leaving certificate geography question as the application of the virtual reality learning environment, this paper purposes a virtual reality class lesson that is highly functional and contains various modes of learning outside of text-based media such as auditory, visual and kinesthetic media elements. The design of this VRLE considers different sources of media that stimulate the user's senses. This includes audio files, UI image pop-ups that contain diagrams, a drawing tool and an interactive game. Its design also focuses on the usability of the system. For example, UI elements such as menus are simplified, the user is given clear instructions and the system does not heavily rely on text to convey information to the user. As usability is lacking in this area, thorough research has been conducted on UX/usability testing to determine what metrics would be best suited to evaluate the environment. The evaluation process consists of the workload of a VRLE being tested against the workload of a typical classroom lesson that lacks multimodal aspects. As well as this, the system usability scale is used to test the VRLE's usability. Based on the results of the testing, the quality of the VRLE's usability can be established.

Declaration

No portion of the work referred to in this thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institution of learning.

Signed:
Ruairí Horgan

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1 Introduction

An early explanation of virtual environments is that they are illusionary environments that are accessed through the use of a head-mounted display (Ellis, 1994). Their potential for use in education ranges from various training programmes in different fields, to exploration of remote locations such as outer space. In the past couple of decades, these potentials have come to fruition. Specifically, since HMDs have become more available with the introduction of affordable headsets such as the Oculus Rift, their use in the field of education is being given more attention than it ever has before. However, as this is a very recent occurrence, the available literature and research in this area are currently limited.

From the work that is currently available, there are a couple of key aspects that should be fundamental to virtual reality learning environments (VRLEs) that have been given very little attention. The first aspect is multimodality, which refers to multiple types of media-based representation. Philippe et al. (2020, p. 422) claim that "the use of VR in the context of multimodality for teaching and learning has not been investigated yet". As of March 2020, there had been zero search results on 'Science Direct' for peer-reviewed articles published between 2010 to 2020 when terms including 'VR' and 'multimodality' were used in the same search. The second aspect is usability. When carrying out broad research in the area of VR for this project, it became clear that user experience testing and the overall usability of systems were not being given enough attention. Narrowing the research to exclusively consider VRLEs highlighted this issue even further.

This project proposes a collaborative VRLE that takes these two neglected aspects and emphasises them as the core foundations of its design. It will give thought to what multimedia aspects can be included in a virtual environment (VE) to stimulate various senses of the user and the application will be created with ease of use in mind. Typically, VRLEs take advantage of the technology's capability to educate students in areas and settings they would not usually be able to access. Commonly explored VRLEs include science labs and field trips. To further ensure the novelty of the proposed VRLE, the application of its design will be a desert biome adapted from a leaving certificate geography question. Instead of completing usual field work activities, students will learn about the environment they are in by interacting with various objects in the scene and by listening to the teacher present.

With the exception of the 'Introduction' and 'Conclusion', this thesis will be separated into five different sections titled 'Literature Review', 'Design', 'Implementation', 'Evaluation' and 'Future Works'. A brief description of each section is as follows:

- Literature Review: This is dedicated to analysing any past works that may be relevant to the VRLE that is being proposed. It will be separated into different sections based on theme. Such themes include multimodality, immersion, etc.
- Design: The various considerations that went into designing the VRLE will be considered here. Sub-headings based on design considerations will be used.
- Implementation: This section will detail how the project was built and what considerations from the 'Design' section were successfully implemented. As well as this, any shortcomings in relation to implementing the design will be

mentioned. Solutions and alternative approaches to these shortcomings will be detailed.

- Evaluation: A test to examine the usability of the VRLE will be carried out and compared against a control group that is taught a lesson in a traditional classroom setting that lacks multimodal aspects. As this project has a focus on usability, a brief research section will also be included in regards to how the chosen metrics were decided upon.
- Future Works: As the proposed VRLE has to be completed in a restricted time frame with a limited amount of resources, the finished prototype will be something that could be expanded upon further. This section will investigate if any absent features could be implemented in the VRLE in the future.

2 Literature Review

As outlined in the introduction, multimodal learning and usability are the focus of the proposed VRLE. This is reflected in the work presented in the literature review. Both terms will be explained in detail, with particular attention given to their application in VR and VRLEs. As well as these two topics, any relevant information has been collected and given a sub-heading. This includes areas such as immersion in VR, geography and VRLEs, designing a VRLE etc. The work carried out here will act as the foundation for how the design of the VRLE will be approached.

2.1 Multimodality

To summarise simply, 'multimodal' refers to more than one mode of representation. Instead of text-based representation alone, it also includes elements of design that are visual, auditory and kinesthetic (Lim et al., 2022). Kinesthetic learning refers to using physical activity to learn. For example, a frisbee being thrown by a student could act as a metaphor for the transfer of control (Begel et al., 2004).

2.2 Multimodality and VR

As mentioned in the introduction, a true multimodal learning experience has yet to be explored in the context of VR. However, there are references to multimodality and VR found in some of the currently available literature. Martin et al. (2022) argue that multimodality plays a fundamental role in VR as multimodal sensory input is critical to creating the feedback needed to dictate a VR experience. In the context of VR educational experiences, they surveyed previous works to see what senses other than vision were stimulated during a session. Their results showed that no previous work stimulated audition, proprioception and haptics altogether in a single session.

Philipe et al. (2020) suggest that in relation to VR multimodal learning, the opportunity for students to engage in self-regulated learning could offer them a better quality of retention and experience. While they observed a lack of research on multimodality in VR education, they point out there are previous works that are relevant to the area. For example, they refer to Dickey's (2003) case study on using a virtual chat-tool in multimodal learning. Results from this case study displayed that interaction and responsive feedback as well as the presentation of multimodal information as visual illustrations were the main learning affordances of the students taking part in the study. Philipe et al. (2020) also refer to a study by Doumains et al., (2019), which involved comparing a multimodal VR Learning group with a control group. They found that multimodal interactions within VR seemed to improve learning in comparison to the non-multimodal control group. Central features included speech control and virtual representation.

2.3 Usability and UX

Usability is a core focus of HCI (Human Computer Interaction). It is defined in ISO 9241-11 as "The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" (Dix, 2009). Effectiveness considers the user and the achievement of goals with accuracy. Efficiency considers how little resources (e.g. time) had to be used to achieve the goal. Satisfaction considers if the user's experience is a comfortable one or not. UX (User Experience) is defined similarly but differs in its broadness. It considers the user, the system and the "environment within which the interaction takes place" (Berni & Borgianni, 2021, p.1628). The interaction between the user and the system creates experiences that are ergonomic, cognitive and emotional. Research into evaluating user experience can be found in the evaluation section of this thesis.

2.4 Usability and UX in VR and VRLEs

Research into usability and UX in VR dates back over two decades ago, not long after the term 'user experience' was first coined. Marsh's (1999, p.62) work can be looked at for example. He notes that the design of the standard 2D graphical user interface may not be appropriate when designing 3D interfaces. The paper concludes that switching from 2D UIs to 3D UIs "introduces issues such as, awareness, presence and immersion within the VE".

2.5 Immersion

Immersion is a term that frequently appears in the current literature available concerning VR experiences. In the context of VR, it can be described as the involvement of a user in a VE. The VRE's use of stimuli such as sound and images create a sense of presence for the user (Radianti et al., 2020). The more immersive the VR experience is for the user, the higher the sense of presence is felt. The capabilities of VR technologies allow for the opportunity to provide users with the experience of both sensory immersion and being inside a simulated world (Mikropoulous & Natsis, 2011). Previous technologies lack these capabilities. VR offers "head and position tracking to various degrees and HMDs render a different image for each eye, creating visual cues for depth perception and a realistic first person perspective" (Makransky et al., 2020). As well as this, it offers a greater visual field than a standard monitor. For the reasons listed here, a user interacting with a VE using a 2D desktop display is considered a low-immersive experience while a user interacting with a VRE through the use of a HMD is considered a high-immersive experience. A study that solidifies VR as more immersive than desktop displays is the work of Shu et al. (2019). In this study, an earthquake education VRE was created. A group that experienced it through a desktop monitor was compared to a group that experienced it through a HMD. The HMD group reported that they felt a higher sense of immersion and spatial presence than the desktop group.

Available literature suggests that a higher sense of presence felt in a VRLE can positively affect a user's experience. Previous research posits that IVR (Immersive Virtual Reality) has the potential to increase ratings of presence and enjoyment as well as scores on tests of learning. In particular, Makransky et al.'s (2021) study can be examined. It involved the comparison of two groups in relation to instructional effectiveness. One group consisted of participants being placed in a learning environment in IVR while the other group consisted of participants watching instructional videos. In their first experiment they found that while the IVR group did not experience greater learning, they did experience both enjoyment and a sense of presence. They stated "students feel significantly more presence when learning through an IVR simulation as compared to learning with a video." (Makransky et al., 2021, p.729).

While a higher sense of presence is equated with a positive experience for the user in VR, there is literature that suggests it may have negative consequences as well. Ahn et al. (2022, p.3) note that there is a correlation between an increase in spatial presence and an increase in engagement and enjoyment of mediated content. However, a higher spatial presence in VR is likely to have a negative effect on "both the perceptual and cognitive processing of information by placing constraints on the available resources but also by diminishing the information value of the stimulus that is insufficiently processed." Their first study featured participants experiencing a VR learning session about climate change in a virtual ocean. Another group featured participants experiencing this lesson through the use of a computer monitor. From this study they found a correlation between students who felt a higher sense of spatial presence and students who were able to recall less information. Parong & Mayer (2018, p.3) also note a similar issue. They suggest that extraneous material negatively affects a learner's experience as it "disrupts the process of organizing the material, and may prime the learner to integrate the material with prior knowledge in an inappropriate manner". In an immersive VR lesson, factors that could be considered as an extraneous feature would be the constant animation cycle the learner is immersed in. Participants in Ryan & Poole's (2019, p.414) study on the impact of VLEs on student satisfaction, engagement, recall and retention showed that while participants experienced enhanced engagement and enjoyment, there was little difference in retention (in comparison to a VLE group and a non-VLE group). As well as this, learning styles "had no significant impact on the outcome".

2.6 User Interface (UI)

User Interface accounts for the interaction between users and the system. The ISO states that there are four standards that should be adhered to in UI design; consistency, higher quality, comfort and product evaluation (Bevan, 1989). With specific reference to educational systems, the user interface should cater to novices who may not be familiar with the system. Main features of the UI should include "Overview, navigation support and recommendations" (Oppermann, 2002).

2.7 UI and VR

Currently, there is a lack of research in the area of UI design in VR. An issue with many current VR applications is that they can "either support only simple interactions or have serious usability problems" (Kharoub et al., 2019, p.2). Successful application of 3D UIs in VR lack complexity. More immersive design choices, such as complex scientific visualisation are extremely difficult to design and evaluate. While there is a current lack of work on UI in the context of VR, there are a limited number of papers that could be useful when designing a VRLE.

Kostov & Wolfartsberger (2022) designed a multi-device VR training app. The UI elements that feature in their design match Kharoub et al.'s (2019) observation relating to a lack of complexity. They recognised that reducing the complexity of the VR environment meant that inexperienced users would not encounter as many issues while using controllers and would not have to complete as many tutorials. They also stated that spatial integration was a key component of UI in VR. The ‘world space’ offered UI features to be set up anywhere in the environment. Outside of the ‘world space’, UI features could be attached to the controllers and also the player’s vision. They also implemented laser pointers, which are a common tool in VR used to attract user attention to UI elements and specific objects in a VE.

An example of research with a specific focus on UI in VR is Sun et al.’s (2019) work on UI design for high learning performance in VR-based architectural applications. They note that UI design for VR is currently limited and that it is essential to examine UI design in VR applications to improve the learning experience of students undertaking VR architectural education. Their study found that learning performances in VR are affected by different UI designs. They also found that ‘fishing mode’ is preferable to ‘flying mode’. Fishing mode can be described as the user having the ability to point at a destination and being able to instantaneously move to that destination. Flying mode means the user can move themselves to any accessible place in a scene as if they were flying.

2.8 Virtual Reality Learning Environments

A Virtual Reality Learning Environment is a VR environment that is used in an educational setting to overcome various issues that would be encountered in the absence of one (Coban & Göksu, 2022). Such issues include distance learning, the ability to hold field trips in places that would not be accessible otherwise, overcoming problems with class size etc (Bricken, 1991). Their purpose should be to allow users to have experiences that normally could not be had otherwise. They can overcome financial, physical and practical constraints (O’Connor & Domingo, 2017).

2.9 Geography and VRLEs

Current literature reveals a range of studies concerning VR and geography education. In relation to teaching geography in school settings, Stojšić et al. (2017, p.90) suggest that Google Cardboard would be an effective tool to create immersive experiences. Specifically, it would offer students to experience a VR version of Google Earth, allowing students to experience virtual trips through the use of the expeditions application (Each trip is a “collection of several 360° VR panoramic photos on particular topic”) and more. Research carried out by Jong et al. (2020, p.2065) also sees Google Cardboard being used in an educational setting to teach a geography class. Students were taught physical geography lessons through SV-IVR (Spherical video-based immersive virtual reality). SV-IVR allowed students to be situated in a “360-degree human-recorded real-world environment, bringing their consciousness into other times and spaces, and allowing them to explore (observe and listen to) the environment in any directions”.

These two examples looked at are based in a secondary school setting. Bos et al. (2021) look at applying VR to teaching undergraduate and postgraduate geography students. Similarly to the past two examples, 360° images and videos were used in the VR experience. Students were able to experience landscapes they would encounter on a field trip before being allowed to complete practice field work. For example, they were able to identify risks of the landscape, such as uneven terrain.

A common trend that appears in the research looked at so far is the use of 360° video. The work of Lv et al. (2017) takes a different approach to this. They propose using VR GIS technologies to allow learners to visualise and interact with geospatial big data. A simple definition of big data is that it is "Complex, unstructured, or large amounts of data" (De Mauro et al., 2015, p.102). An example of an application scenario of this concept would be a user using their hands with no controllers to manipulate a 3D GIS visualisation.

2.10 Designing a VRLE

Before work can begin on designing a VRLE, past works that focus on design should be looked at. Johnson-Glenberg (2018, p.2) suggests that there are a lack of guidelines in relation to making "optimal education content in VR". She argues that the two affordances that should dictate such guidelines are "the feeling of presence" and "embodiment and the subsequent agency associated with manipulating content". She created a list of guidelines based on her study. It is suggested that the user should be assumed as a novice in the use of VR technologies. UI elements should be limited to not overwhelm the user. Exploration elements should be guided and not completely free. Consultations should take place between the teacher and the person designing the VRLE prior to the VRLE being used on students. Text reading should be minimised. Immediate feedback should be given to the user. When designing educational content in VR, having a synched multiplayer feature should be a goal.

In Liaw et al.'s (2019) work on designing and evaluating a 3D VRLE, they noted that 'technical hiccups' was a theme that emerged in the evaluation stage after holding focus groups with participants in the study. Problems that occurred included issues with audio and sound in relation to the chat feature implemented. This affected communication among the participants. Navigation issues were also highlighted. They noted that simple button press navigation was preferable to what was offered in the first round of studies.

O'Connor & Domingo (2017) argue that repurposing and reusing currently available VR environments would be beneficial to both developers and teachers wishing to design their own VRLEs. It would be a cost-effective approach that would eliminate many technical challenges that would be encountered otherwise (e.g. low-level networking). Their study looks at using existing virtual worlds known as 'islands' in 'Second Life' as the basis of the design of VRLEs. 'Second Life' can be described as a 3D social network "where people can collaboratively create and edit objects in the virtual world" (Boulos et al., 2007, p.233). Saunier et al. (2016) suggest approaching the design of VRLEs in a similar manner. They propose a methodology for designing VRLEs that can be adapted by teachers so they can implement their own "scenarios according to the level of the trainees and to the pedagogical objectives".

2.11 Conclusion

Judging the previous works on usability and multimodality in VR education, it is evident that more research needs to be carried out in both areas. Regarding usability, it would be optimal to ensure that the VR experience is immersive. The user should feel like they are in the world being presented to them. UIs for VR is an area that needs more exploration. While designing the proposed VRLE, a choice must be made between using a typical 2D interface to ensure functionality and ease of use, or a more complex 3D system could be designed. Regarding multimodality, it is evident that there is a shortage of VRLEs that incorporate multimodal aspects. This should be addressed in the design of the proposed VRLE. Examining the previous work on VR geography education reveals that 360° videos are frequently the basis of previous studies. To continue to develop on this would not lead to a novel VR experience. A different approach should be considered when designing the VRLE. Reusing existing environments in 'Second Life' saves time and makes designing a VRLE a less difficult process. A similar approach should be taken in designing the VRLE, such as reusing existing assets.

3 Design

3.1 Scene Design

The initial step taken for creating a VR project is to create a scene. Various APIs can be used to do so depending on what the use of the application is. One such way to do so is by using Three.js. It is a "3D library that tries to make it as easy as possible to get 3D content on a webpage" (How to Create VR Content, n.d). After constructing a scene, the webpage can be made accessible by simply importing a VR button, enabling XR rendering and using setAnimationLoop() instead of window.requestAnimationFrame() (How to Create VR Content, n.d.). Once this is done, the user can visit the webpage using a HMD.

Another API that can be used to construct a scene is the Unity3D engine. Unity is a game engine that allows the user to build 3D environments that can have VR capabilities implemented into them (Keil et al., 2021). Unlike Three.js, it is not a web-based application. Unity's scripting language is C#. Much of the research featured in the literature review section detailed the use of Unity to create VR applications (Saunier et al., 2016, Kharoub et al., 2019 & Keil et al., 2020).

As previously mentioned in the thesis, an advantage of having a class in VR is that there is a potential to hold field trips that would not normally be feasible otherwise. While the use of VR and field trips have been previously explored, a novel aspect that could be explored is constructing a field trip based on a leaving cert question. Questions could typically be taught in a manner that lacks multimodal elements (such as text-based bullet points on a desert biome being projected on a whiteboard). There is novelty in taking this typical lesson and creating a virtual reality environment based on it.

This proposed design will consist of two scenes the user can switch between; the classroom scene and the desert scene. In the classroom scene, the teacher can briefly teach the students about the lesson. They can use the whiteboard to depict visual media, such as images and graphs. Once the students are prepared, they will be transferred over to the desert scene. Students will be guided by the teacher in the desert biome, but they will also have the opportunity to independently navigate the scene. The UI tools and interactive elements of the scene will include features relevant to multimodal learning. This will include an interactive game with grabbable objects that can be examined, audio components, images of relevant material such as diagrams, videos that the student can watch etc. To create the initial scenes, all objects that serve an aesthetic purpose should be imported as an asset.

3.2 Networking

As multiple users will be using the classroom simultaneously, networking must be implemented into the application. Unity3D applications do not have networking built in (About Netcode for Game Objects, n.d.). However, Unity released a solution to this called Netcode. Netcode is a high-level networking library that allows the developer to "send GameObjects and world data across a networking session to multiplayer players at once." This would be highly advantageous to a project like this as time is too limited to learn about low-level protocols and networking frameworks. Other solutions include third-party services such as Normcore and Photon that also provide a high-level approach to networking (Normcore, n.d., Photon, n.d.).

3.3 Voice Chat

Voice chat can be implemented into the project using one of the previously mentioned third-party services. In relation to Normcore, after it has been integrated into the project through the use of a plug-in, the developer can add the 'RealtimeAvatarVoice' to include it in a scene. This single component will create an 'AudioSource' component that can be spatially customised. It features properties such as a 'mute' and 'voiceVolume'. The former allows the local player to stop sending audio while the latter reflects the last sampled audio level. It also includes an AudioProcessor that automatically "sets the gain for the microphone and filters out background noise, reverb and echo cancellation" (Voice Chat, n.d.).

A common usability problem in networked multiplayer applications is poor support and implementation of a voice chat feature (Pinelle et al., 2009). The proposed VRLE requires a voice chat feature that can provide users with an effective form of verbal communication to better facilitate multimodal learning. As a third-party service such as Normcore provides a high-end approach to implementing such a feature into a Unity3D project, it would be beneficial to use this as a starting point to have a voice chat in the project that is reliable and relatively easy to implement.

3.4 Classroom Scene

The classroom will be the second scene the user encounters after the initial main menu scene. The classroom scene is intended to replicate a typical classroom setting. Studies have shown that the level of realism featured in a VRE can positively affect the user's sense of presence (Newman et al., 2022). This will be considered when designing the classroom scene. The imported classroom model should be one that would replicate what a student would normally see in a classroom. Consideration will also be given to aspects such as spatial constraints and other affordances that may impact the level of realism that the environment will have on the user.

Figure 3.1: Realistic VR Classroom Example

As previously stated, the design of the desert will be primarily based on UI elements and multimodal aspects.

3.5 Multimodal Design

The design of the VRLE will be primarily based on UI elements that have the potential to aid in multimodal learning. The following are features to be included in the project.

3.5.1 Menu System

While 2D menu design for interfaces has been given considerable attention in design literature, this has not been the case for 3D menu design and VR (Jin & Lee, 2019). UI menus in VR are often 2D planes consisting of buttons, sliders and other widgets that the user can interact with. Wang et al. (2021) conducted a study to determine if users preferred a fixed or a handheld menu in VR. Based on a TLX questionnaire (see page 59 for a definition), results showed that in terms of accuracy and speed, the fixed menu was optimal. As well as this, the task load level for participants was recorded as lower. This displays that it was the more satisfactory system to use for the participants.

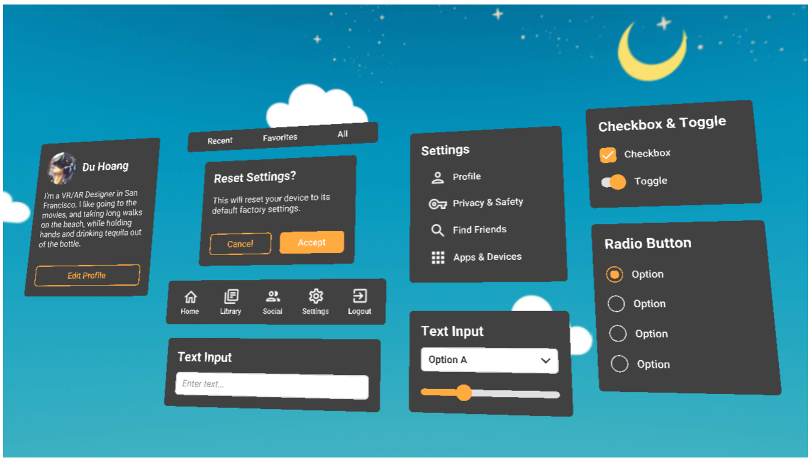

Figure 3.2: 2D UI menu system example

Based on these findings, this project will incorporate a simple fixed menu system. This will include an introductory main menu screen typically seen in VR applications. The simplicity of use that it will encompass should benefit the system's overall usability. While the proposed project does not include general options that the user can manipulate, the menu could include instructions instructing the user about the general controls of the application.

3.5.2 Drawing Tool

The classroom of the application could include a drawing tool that the teacher and/ or students could use. Drawing as an element of multimodal education, aids students in fostering a "deeper understanding of concepts more than simply viewing drawings"

(Smith et al., 2019, p.4). It can also help with student engagement and text comprehension.

Research into drawing tools is not uncommon in relation to VR. Some of the work carried out takes spatial advantage of the VRE and includes drawing tools that allow for things such as free-hand 3D drawing (Truong et al., 2021). While this is potentially an interesting area to explore, in the context of this VRLE it may not be suitable. Inside the virtual classroom itself, the user could face spatial constraints as it is designed to replicate a normal classroom. As the classroom is more routed in realism than the desert biome trip, such a tool may appear out of place. A more suitable tool could replicate traditional features of a classroom, such as a notebook or a whiteboard.

Figure 3.3: 3D free-hand drawing included in Truong et al.'s (2021) study

3.5.3 UI Interactive Elements

As discussed in the literature review, to create a sense of presence in VR, an element of freedom should be offered to the user (Mikropoulos, 2011). In the desert biome, guided learning will be implemented. However, the user will be able to walk around independently and interact with the scene where possible.

3.5.3.1 Grabbable Objects

Drawing Tool: The drawing tool should include an object the user can pick up and draw with.

Items in the Desert Biome: The user could grab and pick up various items in the desert that they can examine and inspect.

3.5.3.2 Information Points

The desert biome scene could include points where the user could retrieve further information. Interaction with these points could trigger events such as playing audio or displaying video and images (Create user interfaces (UI), n.d.).

3.5.4 Audio Components

As previously mentioned, multimodal learning encompasses multiple streams of media. While voice chat will be incorporated into the project so that the teacher can guide the user, other audio and speech components can be considered.

In the case of the desert biome scene, to encourage the user to explore the area, spatial audio elements could be added. For example, certain points of the scene could be explained to the user depending on where they are positioned, such as audio information about the flora being provided at a point where it is visible to the user. Such ideas have been explored in the past in relation to AR (augmented reality) and guided tours (Bederson, 1995). Applying the same principles based on these past works to the VRLE would stimulate the user to take initiative in exploring the full scene.

3.5.5 Interactive Game

A short game could be implemented to test the knowledge of the student concerning the lesson given. There are various design options that could be taken to create this game.

3.5.5.1 2D- Quiz

In unity, UI tools could be imported so that a canvas feature could be brought into the scene. Similarly to the menu described previously, this canvas could consist of various UI widgets. A simple 'yes' or 'no' button feature could be integrated into this system where if a student answers correctly, they are taken to the next question. If they answer incorrectly, they could be alerted to this.

3.5.5.2 3D- Interactable Game

To further expand on the multimodal aspects, a 3D game that involves the user interacting with objects may be included. A good starting point for the design process would be seeing how could the 2D game be adapted to a 3D setting. One such way would be to have the user interact with objects in the scene. For example, an object in the scene could be matched to a specific area or the user could be asked to complete a 3D puzzle. A 3D game could be more beneficial to the user than a 2D game, as it offers a greater potential to develop on kinesthetic learning in the VRLE. It would involve the user moving around and engaging with the scene they are in.

3.6 HMD

The chosen HMD that the project will be built for is the Oculus Quest 2. The primary reason for this is that it is the most readily available headset in the university where the project is being built. As well as this, the student who is building the project has previous experience in using this HMD. Another reason for choosing the Quest 2 is the Oculus Integration package. This package provides developers support for developing oculus applications in Unity (Oculus Integration SDK, 2022). There has been previous work that has been carried out to suggest the success of building VR learning applications for the oculus through the use of the Unity3D engine (Fang et al., 2021). In the context of the proposed VRLE, the material that is currently available on this subject matter suggests that the combination of Unity3D and the Oculus Integration Package is a suitable candidate for creating an environment that can be easily tested in a HMD.

3.7 Conclusion

Based on its successful application in previous projects its ability to build for the Quest 2, Unity will be used as the primary API to build the VRLE. As a fixed menu system will be implemented in the project, the user interface of the main menu will be 2D instead of 3D. The proposed interactive game will take place in 3D space to avoid the overuse of 2D interfaces. As well as this, it is more suited to the project as it encourages multimodal learning. To ensure that the classroom area of the VRLE is as realistic as possible, the featured drawing tool will replicate what would normally be found in a classroom. The guided tour example referred to under the 'Audio Components' heading should be used as inspiration when implementing audio into the VRLE.

4 Implementation

The description of the implementation of the VRLE's design is presented here in chronological order. The choices made are based on the concluding factors of the previous chapter.

4.1 Project Settings and XR Rig

First, 'Unity Hub' was downloaded. Next, a student account was created via the academic institution to gain access to a free license. The version of Unity first used was 2021.3.6f1. Next, the 3D template was chosen for the project. Before work could begin on the scene, Android tools had to be downloaded and imported into the project so that it could be built for the oculus headset. After this, the 'Oculus XR Plugin' was downloaded and imported into the project. The build settings were opened and the player settings were selected. This opened the player section of the project settings. A suitable API level was chosen (Android 6.0 'Marshmallow' API level 23). Under the XR Plug-in Management section, the build was switched from PC to Android and the Oculus plug-in was chosen.

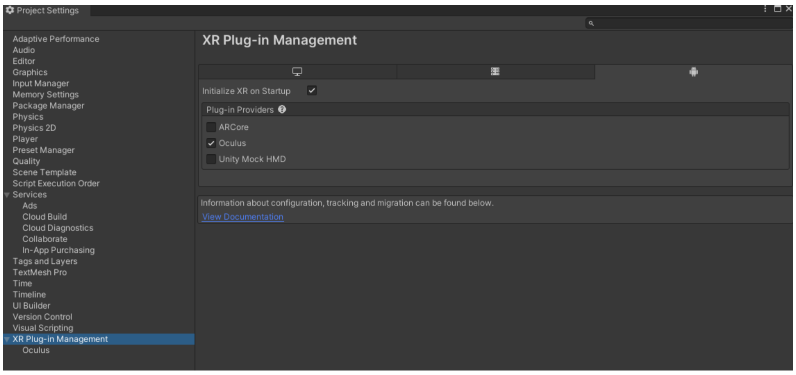

Figure 4.1: Building the application for Oculus

To begin building the scene, first a plane was added, a material was applied to it and the XR-rig was chosen. Using the assets directory, the OVRPlayerController was searched for and added to the scene. The OVRCameraRig dropdown was then selected and the CenterEyeAnchor was set as the main camera. The original camera from the scene could now be deleted. Next, hand models for grabbing objects had to be added. The CustomHandLeft prefab was placed under the LeftHandAnchor and the same procedure followed for the right hand. The player was then set as the OVRPlayerController in the OVR Grabber Script for each of the custom hands. The tracking origin type of the camera rig was set to floor level so that the height of the camera in the VRLE would be determined by the distance between the HMD worn by the player and the floor.

To prepare to test the scene, an 'Oculus Developer Hub' account was created so applications could be downloaded onto the HMD. After this, an attempt was made to create an initial build to test in the HMD but an error was encountered. The gradle package that is part of the Android tools that had to be downloaded to build for the Quest could not be found when a build was attempted to be made. To overcome this issue, the gradle package was removed from the directory and manually downloaded from github and placed in the directory. Once again, the error remained when the build button was clicked. As a colleague decided to use Unity 2021.3.5f1 after encountering a similar issue, this version of Unity was downloaded and used instead.

4.2 Classroom Scene

Once the scene was built using this version of the Unity, a successful build could be made and tested using the HMD. The next action taken was the development of the classroom scene. First, a model was purchased and then imported into the scene. There was an issue as the walls and ceilings of the model appeared transparent from the inside of the classroom rather than the outside. To overcome this, the 'Probuilder' package was downloaded and imported into the project. 'Probuilder' provides 3D modelling tools for Unity projects (Probuilder, n.d.). Using 'Probuilder', the normals of the walls and the ceilings of the classroom model were inverted so that the walls now appeared while the inspector camera and the OVRPlayerController were inside of the classroom and they disappeared when the inspector camera was zoomed out.

Figure 4.2: Once the normals were inverted, the walls and ceilings appeared with a texture inside of the classroom. When the camera was positioned outside, the faces of the walls and ceilings appeared transparent

Now that the classroom model was loaded, work began on implementing UI components. The drawing board was the first component to be considered. A plane was created and resized so that it would replicate a whiteboard. Next, an empty game object called 'Marker' was created. A cube was added to the empty game object and it was resized to an appropriate shape for a handle. It was then duplicated and the duplicate was renamed 'Tip'. This was resized to replicate a tip of a pen. Next, a blue material was created and applied to the tip. The tip was placed on top of the marker. After this, an empty game object called 'Grab Point' was added and altered so it would represent the point that the user had to grab when using the marker. To accommodate the whiteboard, the imported classroom assets were altered so space could be made on the wall facing the student desks. A cube was added to the scene, resized and named 'table'. The purpose of this would be to provide a place for the marker to be situated at the start of the scene.

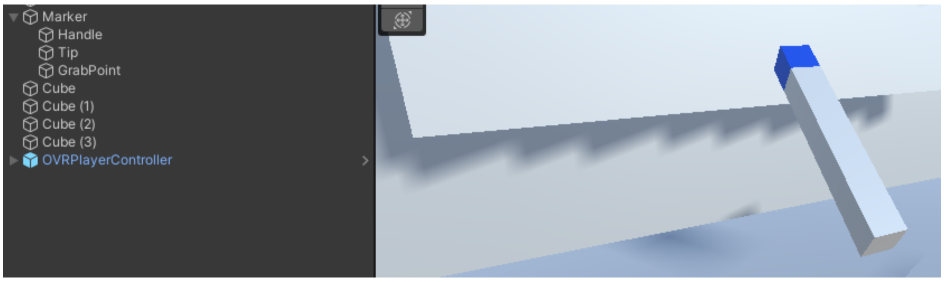

Figure 4.3: Hierarchical structure of marker

Two C# scripts were made. One script was for the whiteboard and the other one was for the marker. In the whiteboard script, the resolution of the whiteboard and the texture of the whiteboard were set. The script was then added to the whiteboard. A tag was then made for the whiteboard. For the marker script, access was given to the tip and a pen size was set (See SerializeFields). Access to the renderer was given so that the colour of the marker would appear on the whiteboard. With a _penSize of 5, the pixels to create the colour on the whiteboard was set to _penSize * _penSize.

Next, the draw method was created to account for how the drawing of the marker occurs. A private RayCastHit variable was created to account for touch. If something was hit in the parameters and had the tag of whiteboard then it would be marked. The _touchPos variable accounted for where the whiteboard was touched. The out of bounds line (if statement) was needed to avoid an error given by Unity. The actual drawing done by the user was accounted for by the if (_touchedLastFrame) statement. The for loop inside this accounted for the percent coverage of the last and current point that the marker touched against. The _lastTouchRot rotation ensured that the position of the marker when grabbed was kept in place when the marker made contact with the whiteboard. The apply line was added so the pixels would be updated. Finally at the end of the script, _whiteboard and _touchedLastFrame were both unset so that if the pen was not touching anything that is not the whiteboard it would unset.

Code 4.1: WhiteboardMarker.cs

```
private void Draw()
{
    if (Physics.Raycast(_tip.position, transform.up, out _touch, _tipHeight))
    {
        if (_touch.transform.CompareTag("Whiteboard"))
        {
            if (_whiteboard == null)
            {
                _whiteboard = _touch.transform.GetComponent<Whiteboard>();
            }

            _touchPos = new Vector2(_touch.textureCoord.x, _touch.textureCoord.y);

            var x = (int)(_touchPos.x * _whiteboard.textureSize.x - (_penSize / 2));
            var y = (int)(_touchPos.y * _whiteboard.textureSize.y - (_penSize / 2));

            if (y < 0 || y > _whiteboard.textureSize.y || x < 0 || x >
_whiteboard.textureSize.x) return;
```

```
            if (_touchedLastFrame)
            {
                _whiteboard.texture.SetPixels(x, y, _penSize, _penSize, _colors);

                for (float f = 0.01f; f < 1.00f; f += 0.01f)
                {
                    var lerpX = (int)Mathf.Lerp(_lastTouchPos.x, x, f);
                    var lerpY = (int)Mathf.Lerp(_lastTouchPos.y, x, f);
                    _whiteboard.texture.SetPixels(lerpX, lerpY, _penSize, _penSize,
_colors);
                }

                transform.rotation = _lastTouchRot;

                _whiteboard.texture.Apply();
            }

            _lastTouchPos = new Vector2(x, y);
            _lastTouchRot = transform.rotation;
            _touchedLastFrame = true;
            return;
        }
    }

    _whiteboard = null;
    _touchedLastFrame = false;
}
```

4.3 UI and Main Menu

A simple user interface was created using the canvas system. First, a canvas was added and the graphic raycaster component was replaced with an OVR Raycaster. UIHelpers were then added to the scene from the assets directory. As UIHelpers already have an event system, the canvas event system was deleted. Next, the size of the sphere that came as part of the UIHelpers was increased and the line renderer of the LaserPointer was enabled. A material was then added to the LineRenderer. Next, the LaserPointer script was edited by adding [SerializeField] on top of the behaviour so that it could be selected in the editor. After doing this, 'On When Hit Target' was selected from the Laser Beam Behaviour dropdown. Next, the button for the joy pad was selected (Secondary Index Trigger). To make the canvas appear as an object, its render mode was set to World Space. The CenterEyeAnchor camera was set as the event camera.

Once this was complete, the size and the position of the canvas could be set. Components were then added to the canvas. A background image button was added and the button was duplicated. The Canvas was selected from the hierarchy and the LaserPointer was added to the OVR RayCaster script. This now provided a template for a menu that could be part of the VRLE. The menu was saved as a prefab and added to the assets. The next consideration was given to adding a main menu system that was discussed in the design section.

A new scene was created and named ‘MainMenu’. Next, a skybox and a plane were added. A material was applied to the plane and the OVRPlayerController was implemented the same way as previously described. Next, the prefab of the menu that was made previously was added to the scene hierarchy and unpacked. The canvas was then adjusted to an appropriate size. The text of the two buttons was changed so the buttons now read as ‘ENTER’ and ‘INSTRUCTIONS’. Next, a logo was added by creating an image and choosing a source for it.

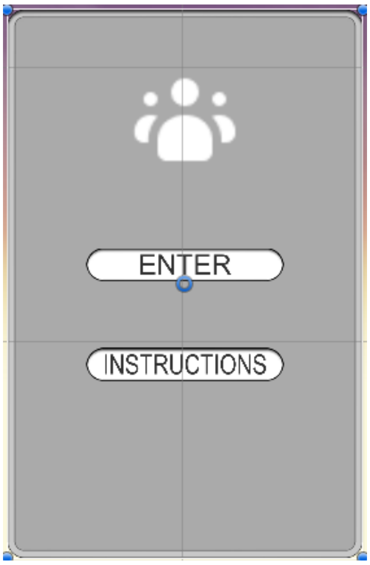

Figure 4.4: UI Menu

A C# script called ‘MenuController’ was made so functionality could be provided to the menu template. In the script, UnityEngine.SceneManagement had to be imported. A function called Enter() was made. The functionality of the button was to load the specified scene (‘MainScene’). Next, in the editor, the enter button was given an on click() function. The menu canvas was added because that’s the object the ‘MenuController’ script was attached to. Then the ‘Enter()’ function was selected.

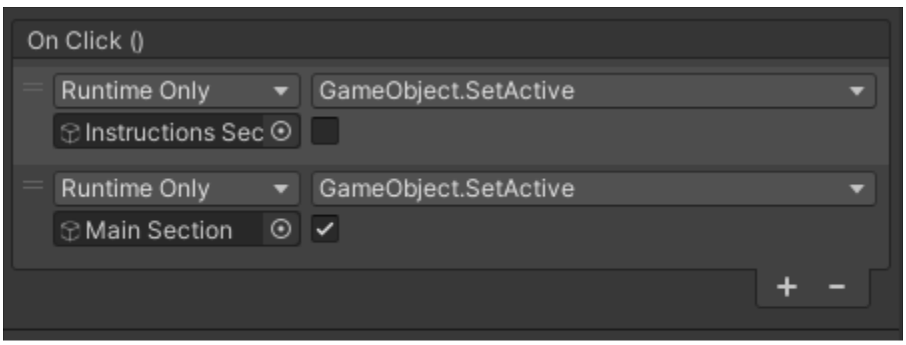

Figure 4.5: The On Click () function to return to the main section of the main menu

Next, the menu had to be split into sections. These two sections were added as empty game objects called ‘Main Section’ and ‘Instructions Section’. The logo and two buttons were added to the main section. The main section was then disabled so the canvas would appear blank. Text was added to the instructions section. This section is where the instructions of how to use the VRLE will be placed once the project is near completion. Next, a button was added to the Instructions Section. This button was called ‘Back’ and the text was changed to ‘BACK’. Next, under the on click() section in the editor, the instructions section was dragged in and under GameObject, SetActive (bool) was chosen. This would allow the instructions section to be disabled when the player clicked the back button. Next, the main section was added to on click() and the same procedure was carried out with the exception of clicking the box that sets it to true. Next, the same thing was done in opposite fashion for the VRClass instructions button. Finally, linear movement and rotation was disabled for the OVRPlayerController so that the player would be in a fixed position but would be able to move their head around.

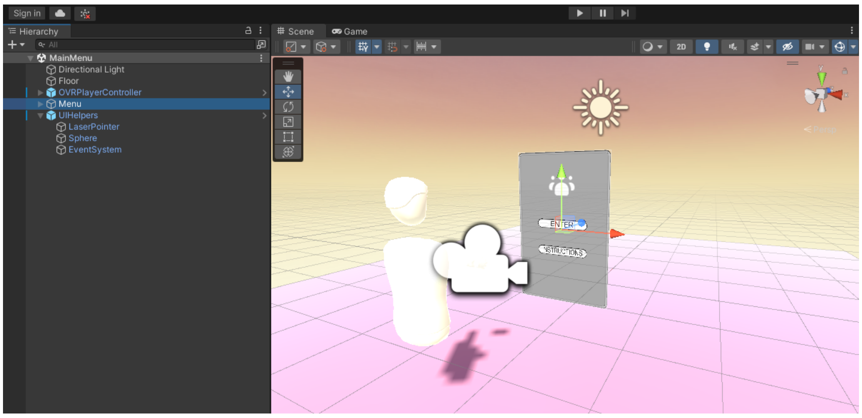

Figure 4.6: Implemented 2D UI in the Main Menu

4.4 Desert Biome

Once the main menu was completed, work began on the desert biome. First a new scene was created. Next, a model was found on the Unity asset store and was imported into the scene. The default directional lighting was deleted from the scene and a skybox that was imported from the assets store was added. The lighting for the scene was then altered by opening up the lighting menu found in the rendering tab and making changes to the environment section.

As previously mentioned, the biome is based on a leaving certificate geography question. In the reference answer, the fauna and flora of the desert were briefly discussed. Specifically, the dromedary camel was described in detail with reference to its adaptations. It was important that the camel would be included in the scene. Using the asset store as well as other third-party vendors such as ‘CGTrader’, a camel model was searched for. Most results were either unsuitable for the low poly environment or they were too expensive to purchase. To overcome this issue, “Blender 3.2.1” was used to construct a model of a camel. This was done by using the mirror modifier with a cube that had a cut made down the centre, and then editing the cube to make the shape of a camel. This included making changes to faces, vertices and extruding specific areas. Next, two different colour materials were created. The beige colour was assigned to the entire object. Next, using control R, cuts were made along the surface around the camel's face to represent eyes. A black material was applied to this selected face. Once the modelling was completed, the mirror modifier was applied and the camera and lighting were deleted from the scene so the object could be exported as an FBX on its own. This FBX file was then brought into the assets folder of the Unity project. The camel object was then brought into the scene and resized appropriately.

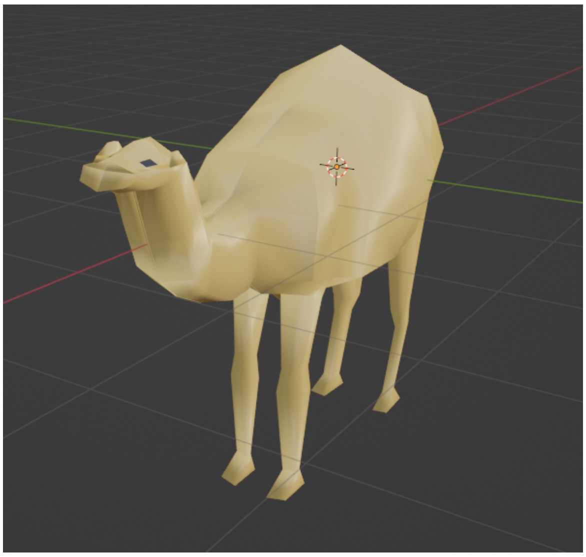

Figure 4.7: Camel object modelled in Blender

The scene now needed to be accessed from the classroom. To make this possible a UI button was placed in the classroom scene. Next, a script called 'SceneSwitcher.cs' was made. Unity.SceneManagement was imported into the script and simple function called playGame() was created. This function switches the scene based on the order of the scenes when a build is being made. The classroom scene was ordered as one and the desert scene was ordered as two. The playGame() function increases the order of the scene it is used in by an increment of one as seen below.

Code 4.2: SceneSwitcher.cs

```
public void playGame()
{
	SceneManager.LoadScene(SceneManager.GetActiveScene().buildIndex + 1);
}
```

As mentioned in the design section, the user should be able to explore the desert biome and interact with the environment. To implement this idea, objects that the user could interact with were worked on. First, a sphere was added and a red material was applied to it. The OVRPlayerController was then given the tag of 'Player'. Next, a canvas was added to the scene and a C# script called 'UI appear' was created. UnityEngine.UI was imported into the script and a private variable called 'customImage' was created. A function called 'OnTriggerEnter()' was created so that if the 'Player' tag was to come into contact with the object the script was attached to, the ‘customImage’ would appear. The same process was copy and pasted with the changes of ‘OnTriggerExit()’ and using ‘false’ instead of ‘true’ so that the image would disappear when the tag of ‘Player’ was no longer in contact with the object the script was attached to.

Code 4.3: UIAppear.cs

```
public class UIAppear : MonoBehaviour
{
    [SerializeField] private Image customImage;

    void OnTriggerEnter(Collider other)
    {
        if (other.CompareTag("Player"))
        {
            customImage.enabled = true;
        }

    }

    void OnTriggerExit(Collider other)
    {
        if (other.CompareTag("Player"))
        {
            customImage.enabled = false;
        }
    }
}
```

Slides that would usually be depicted in a classroom were incorporated into the project. This would be the text element that is part of multimodal learning. Using ‘GIMP 2.10.8’, slides were created based on the reference material. Before creating these slides, consideration had to be given to how text is read in VR. Kojić et al.’s (2020) study found that bigger fonts used in VR displays were not preferred by the users of the system. Results on whether text length was preferrable with regards to how long and short it is was found to vary depending on the HMD used. Regarding their findings, the size of the font was chosen to appear not too large on the image. As well as text, pictures and diagrams were also added to the images created.

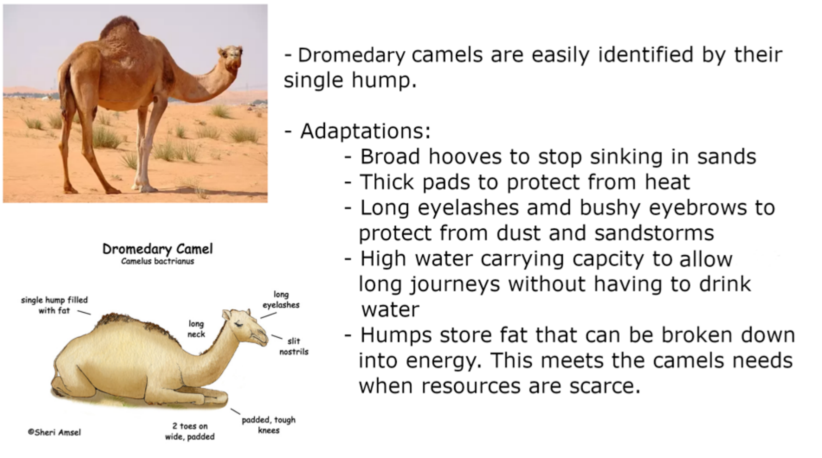

Figure 4.8: Information slide made using GIMP

These images were dragged into the project. Their texture was changed to a 2D image to make them usable as the 'customImage'. Next, an image was added to the canvas and titled 'CamelImage'. It was sized and positioned appropriately. The newly created GIMP image was chosen as the source image in the inspector and it was displayed in the scene. As the image was not meant to appear until the event trigger occurs, the image was disabled.

Under the 'UIAppear' script in the editor for the sphere, 'CamelImage' was dragged in as the custom image. A build was made and now tested. It functioned successfully, and when the sphere came into contact with the XR-rig, the camel information image now appeared. A sphere called 'Cactus Sphere' and an image called 'CactusImage' were also implemented into the scene to provide the user with information about the flora.

4.5 Networking

Unity's 'Netcode' was the first choice for implementing networking into the project. However, the tutorials they provided on their website were too specific to apply to this project (About Netcode for Game Objects, n.d.). Next, 'Normcore' was considered. Initial attempts at its implementation lead to problems with the player controller. After it was imported into the project and an account was made, a key was created to link to the project. 'Normcore' provides an avatar prefab as an asset that could be applied to the project. Attempts at importing this into the scenes lead to the OVRPlayerController no longer working when test builds were made. After going back on the changes made when implementing 'Normcore', the OVRPlayerController still did not work in test builds. After deleting and reconfiguring the player controller, the issue was still not solved. Finally, a new project was made. All the existing assets, scenes and build settings were imported and reconfigured. Functioning builds were able to be made again after this was completed.

A different approach had to be taken to implement networking. To understand networking better, a course called 'Multiplayer Virtual Reality (VR) Development With Unity' was undertaken. The course included an assets folder called 'IRONHEAD Games', which was imported into the project. Following course content, a ‘Photon’ account was made and it was imported into the project. The ‘PHOTON PUN’ app was created on their website, the region was specified and the ID was used to import it into the project. Next, the application needed to be connected to ‘Photon’ servers. To do so, the ‘MainMenu’ scene was going to be adapted to do so. An empty game object called ‘[MANAGERS]’ was created and another empty game object called ‘Login Manager’ was created and added to this. A C# script called ‘LoginManager’ was made to connect the servers. In this script, Photon.Pun was imported and the ‘OnConnected()’ callback method was used to connect the servers.

A C# script was made for joining photon rooms. A room is a shared environment that can host multiple players (Matchmaking Guide, n.d.). This script was called ‘RoomManager’. Of the three available lobby types, the default lobby was chosen for this project. In the script, a hashtable class from Photon was used and inside the hashtable, the value would have to be specified as the two scenes that can be accessed by the player (MainScene and DesertScene). An if statement was included in the OnJoinedRoom() method to check if the room was created or not. A new object called ‘mapType’ was created as the TryGetValue() function returns the value of the key as an object. To prevent confusion, a new C# script was made called ‘Constants’ to avoid making mistakes when writing keys and values by using constant strings instead.

To synchronise the scene for all players, PhotonNetwork.AutomaticallySyncScene = true; was used. Inside the second if statement in OnJoinedRoom(), an else if statement was added for the loading of the classroom and desert scene. A C# script called ‘SpawnManager’ was made for player instantiation. Next, avatar implementation was considered. For this project, it was not essential to have fully functional avatars. However, a basic model would be useful for players identifying each other in the VRLE. First an empty game object was created and the OVRPlayerController was added to this. It was dragged into the assets and saved as a prefab. It was then deleted from the scene. The prefab was then opened. A basic avatar model including a head and a body was attached to the OVRPlayerController. The PhotonView script was added to the prefab so that the avatar could be differentiated from other players in a room (PhotonView Class Reference, (n.d.). In the SpawnManager script, [SerializeField] was added, a game object was made called GenericVRPlayerPrefab and the spawn position was specified. Back in the editor, Generic VR Player was dragged into the Spawn Manager script (In the Spawn Manager Game Object).

Up until synchronisation was implemented, test builds were functional. However, after its implementation, builds were successfully created but would not function properly when tested. In the ‘MainMenu’ scene, the player could not progress to the classroom. After consulting a lecturer for advice, it was suggested that the university’s Wi-Fi had restrictions on network use. To see if this was the issue, the HMD was connected to a different Wi-Fi source and the app was tested again. Once again, the user could not progress to the classroom. To ensure the project was kept up to schedule, it was decided that networking should be omitted from the VRLE. After networking was disabled and packages were deleted from the project, an attempt was made at making a build but it was unsuccessful. After encountering more errors, a new project was made and the existing scenes and assets were imported into this project.

4.6 Audio

Once the project was running successfully, further work could be carried out on the desert scene. The next multimodal aspect to be considered was audio. The spheres in the project could now be further used as information points for the user by the addition of including audio information about the topic of the desert biome. This would also enhance the applications usability as it provided a different form of learning rather than the text based UI pop-ups to users who may have visual impairments. Using the information from the GIMP images, short notes were created. Using a website called text2speech.org that allows for text to be converted to speech for free, speech files were made (Text2speech, n.d.). These speech files were then added as assets into the project.

For the 'Camel Sphere', an audio source was added. A MP3 file called 'camelinfo' was added as the AudioClip. The spatial blend was set to 1 so the sound would be 3D and suitable for VR. With this setting, the audio source becomes louder the closer the user is to the sphere and it becomes quieter the further back the user is from the sphere. Once the spatial blend was set, an issue was encountered. The settings for playing the audio were restricted to 'Play On Awake' and 'Loop' in the editor. When 'Play On Awake' was checked, the MP3 file instantly played when the user entered the scene. When 'Loop' was checked, the file continuously looped.

To overcome this issue, a new #C script called 'SoundTrigger' was made. This script would allow for the sound to trigger once a collision was triggered between the user and the sphere. However, an issue noted when testing this in a HMD was that the event would keep triggering when the XR-rig was close to the sphere. This caused the same MP3 file to play over itself if the user made contact with the sphere. To overcome this, a new approach had to be taken.

A new #C script called 'PlaySound' was made. This script allows for the audio to play and not repeat itself once the sphere collides with the user. The class alreadyPlayed is a Boolean one that is equal to false. If the event is triggered (the MP3 file is played (alreadyPlayed = true;)), then OnTriggerEnter() could not occur again.

Code 4.4: PlaySound.cs

```
public class PlaySound : MonoBehaviour
{
   public AudioClip SoundToPlay;
   public float Volume;
   AudioSource audio;
   public bool alreadyPlayed = false;
   void Start()
   {
      audio = GetComponent<AudioSource>();
   }

   void OnTriggerEnter()
   {
      if (!alreadyPlayed)
      {
```

```
            audio.PlayOneShot(SoundToPlay, Volume);
            alreadyPlayed = true;
        }
    }
}
```

4.7 Interactive Game

Next, the interactive game was implemented. Based on the different games that were proposed, the 3D one was chosen. The 3D game simply involves matching a statement as true or false representative of the colour of a sphere. Using Blender, 3D models were made for the container holding the spheres and the two containers (tick and X) that the user would match the sphere with. They were then imported into the project and scene. The spheres were added and a colour was assigned for each one. Instructions for the game were then added using the same method as the UI image pop-ups. Next, a build was made to examine the initial usability of the game.

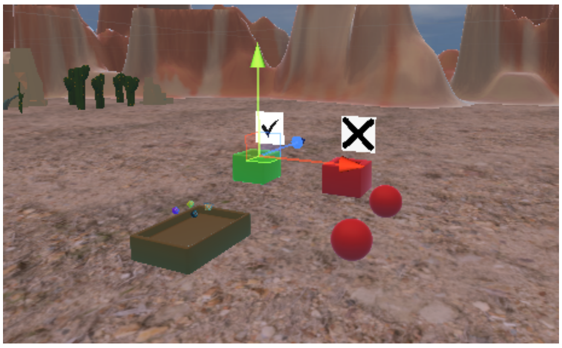

Figure 4.8: 3D Interactive Game

The first issue noted was that the spheres were very difficult to grab. The user would have to physically bend over to pick one up and if the sphere was dropped on the ground, they would have to bend over to pick it up again. Another issue noted was that the box colliders that were added to the objects imported from blender were not suitable for their shapes. Initially, the size of the colliders were adjusted but this was not an efficient solution. To overcome this issue, the colliders were deleted from these objects. Next, a series of cubes were added and adjusted to size to fit the shape of the extrusion in the containers. Each one of these cubes had a box collider. For each container, their corresponding cubes were added under them in the scene hierarchy. The mesh renderer was then disabled for each cube. Once this was complete, the spheres could now spawn successfully in the container and could be more easily moved to the green or the red container. After this issue was resolved, the grabbing of the spheres had to be addressed.

As the ordinary grab component of the custom hand's left and right was affecting the system's usability, they needed to be replaced. DistanceGrabHands were added instead of the custom ones. Then a new layer was made for spheres and titled 'Grabbable'. A distance grabber script replaced the OVR grabber script for the DistanceGrabHands. The player transform was set to OVRPlayerController, anchors were added as the parent transform and the controllers were set to touch in the editor.

DistanceGrabHandLeft had to be edited to have the same features as its right counterpart. The hands were set to grab objects in layer 6 (Grabbable) and a max grab distance was set. The obstruction layer was removed. The animator component was set for both hands. The OVRPlayerController was changed to the ignore raycast layer. An empty game object was made and titled GrabManager and added to the XR-rig. The grab manager script was added as well as a sphere collider that would determine the grabbing distance based off of its radius. The GrabManager was set to the default layer. Next, another empty object called 'Distance Grabber Sample' was made and the Distance Grabber Sample script was added to it. Both hands were then added.

To make the spheres distance grabbable, a 'DistanceGrabCubeCrosshair' had to be imported from the assets store. This was unpacked completely and a prefab was created for the crosshair alone. For each sphere, the OVR Grabbable script was replaced with a Distance Grabbable one. The crosshair was then added to each sphere and was resized appropriately. The spheres were then set in the grabbable layer. Now, when tested in the headset, it was easier to grab the spheres and interact with them.

A functional foundation for an interactive game was now made. Next, visual feedback based on whether the user was correct or not was added. To achieve this, the scripts for the UI elements that were previously implemented were taken as a source of inspiration. If a user was correct, a visual image indicating so would appear and if the user was false the same thing would occur. Firstly, tags were made called 'STrue' and 'SFalse' indicating whether the statement associated with the sphere was true or false. Next, two cubes were added, had their mesh renderer disabled and were resized to fit the base of the red and the green container. Two images were imported into the project and added to the scene. They both were placed in the same position and given the same size. One image was named 'Smile' and the other one was named 'Frown'. A source image that correlated with the image name was attached to both images. After this, the images were disabled.

As this proposed VRLE is a prototype, functionality of this game was limited to the black statement sphere to begin with. Two #C sharp scripts were made called 'StatementsVer' and 'StatementsVerFalse'. As the statement for the black sphere was true, it was given the tag of STrue. The StatementsVer script was attached to the base of the green box and the StatementsVerFalse script was attached to the base of the red box. The scripts detail that if a collision was detected between an object with the tag of STrue and the bases of the boxes, then an image would appear. If the collision was no longer detected, then the image would disappear.

Code 4.5: StatementsVer

```
public class StatementsVer : MonoBehaviour
{
   [SerializeField] private Image customImage;

   void OnTriggerEnter(Collider other)
   {
      if (other.CompareTag("STrue"))
      {
         customImage.enabled = true;
```

```
        }

    }

    void OnTriggerExit(Collider other)
    {
        if (other.CompareTag("STrue"))
        {
            customImage.enabled = false;
        }
    }
}
```

Conclusion

Due to the interest of time, the interactive game was the final element included in the VRLE prototype. While networking was not implemented successfully into the project, the work was recovered and a successful build could be made. As the VRLE was now functioning, work could begin on assessing the system.

5 Evaluation

Now that a prototype has been built, an evaluation of its usability can take place. A comparative study will be used to see how the usability of the multimodal VRLE compares against a traditional classroom environment that lacks multimodal aspects in terms of usability and educational effectiveness. The project that has been built includes many features that will be absent in the traditional class. The aim of this study is to highlight any advantages or shortcomings this approach to learning has in a VRLE.

5.1 Summary of Proposed Study

This study had participants split up into two different groups.

5.1.1 Traditional Class Group

This group of four participants was taught a lesson based on the leaving cert question in a traditional class setting. They were shown a word document that was made by a teacher that consisted of text-based information only. The teacher read this information to the students and at the end of the session asked questions. Once the lesson was complete, the students completed the NASA-TLX questionnaire.

5.1.2 VRLE Group

This group of four participants was taught an interactive lesson based on the same topic through the use of a HMD. As networking was no longer featured in the project, each of the four participants had to complete an individual lesson. Using casting, the point of view of the student was streamed to a desktop display. The teacher was able to guide the participant and teach the lesson as they could observe what the student was doing at all times.

Participants for this study had prior exposure to second level education but did not take leaving cert geography as a subject. The study was carefully explained to them and they were given an information sheet prior to the study taking place. The duration of the study was approximately 15-20 minutes. After the study, a debriefing session took place for the VR group to ensure that they were okay. Further information regarding this can be found in the ethics approval application form.

As UI elements are integral to this project, the type of questionnaires used should reflect this. The two chosen questionnaires were the SUS (System Usability Scale) and the NASA-TLX (Task Load Index). The following two sections detail the research that was carried out to decide why these metrics were the most suitable ones for this project.

5.2 SUS

The SUS index was created to be a simple scale that indicates the usability requirements of effectiveness, efficiency and satisfaction while still remaining as general as possible. It considers the user's ability to complete tasks, their efficiency in performing tasks and their reactions to the system they are using. It is a Likert Scale, meaning that the users indicate a level of agreement or disagreement based on a five point scale (Brooke, 1996).

This scale was chosen for this project as it is easy to apply and allows for a low-cost assessment of a system's usability. The "quick and dirty" nature of the index would ensure minimum frustration from the participants of the study, as it consists of only ten statements that the participants have to respond to. In practice, the SUS has proved to be useful when there is limited time and resources available (Perez et al., 2013). The UI tools such as the spheres with image pop-ups, menu selection elements and the whiteboard tool can all be held accountable through the use of this tool because of how general it is.

5.3 NASA-TLX

As well as the SUS questionnaire, participants will be asked to complete the TLX (Task Load Index). The purpose of the TLX is to provide an "overall workload score" based on how the user scores in relation to the six subscales that the metric consists of (Hart et al., 1988). The six subscales are mental demand, physical demand, temporal demand, effort, performance and frustration. The scale remains relevant in present day, as it is used when testing the workload index of various new kinds of applications.

As user experience and performing tasks are an essential component of this project, it would be useful to include the TLX questionnaire. In this VRLE, the user will have to complete tasks such as navigating from the class scene to the desert scene as well as completing the object grabbing statement game. Such tasks are applicable to each of the subsections that have been listed. The inclusion of the TLX as a form of assessment will give an idea of the workload that is placed on the user in such situations.

5.4 Further Assessment of Each Application

While it is evident that both scales are suitable for this project, there are still issues that arise based on the choice of the SUS and the TLX. While the overall appeal of both of the chosen metrics are their simplicity, there is a case to make that taking a generic approach to UX measurement is not effective. It can be argued that for more efficient UX testing, generic UX metrics need to be "challenged and refined" (Lallemand & Koenig, 2017).

After considering the criticisms noted here, further use of UX scales has been looked at. The work of Chertoff et al. (2010, p.104) is of particular interest as they sought to construct a questionnaire that specifically considers virtual environments. They intended to expand upon questionnaire work that considers a user's presence in an environment. Such previous work includes the Slater-Usoh-Steed questionnaire and the Witmer-Singer Presence Questionnaire. They noted that "Both the PQ and SUS failed to produce significantly greater presence scores for a person in a real environment than in a virtual one".

Chertoff et al.'s, (2010) proposed questionnaire creates a series of heuristics that fall under five different categories relating to the dimensions of experiential design. These categories are the sensory dimension, the cognitive dimension, the affective dimension, the active dimension and the relational dimension. After testing their proposed scale of 24 statements on a group of participants, they were able to eliminate seven questions.

From the 17 statements they propose, two were included in the questionnaire that has been proposed for this project. They were chosen based on the process of elimination. First, all questions relating to storytelling and haptics were disregarded as they were not relevant to the project. Secondly the remaining statements were each compared to those that are included in the SUS and the TLX. All questions that were of a similar nature were disregarded as they would offer no new information. Statement 11 relates to task completion and statement 12 relates to the active design component.

It is important to note that the work of Chertoff et al., (2010) relates to usability as game usability is one of the four categories of HEP (Heuristics for Evaluating Playability). As well as this, it is important to note that the virtual environment they tested on was a console game. Unlike the VRLE, this game is not an immersive environment. Their scale has yet to be tested on a VR game or application.

5.5 Health Considerations/ Ethical Issues

An ethical issue that may arise during this study is that the participant may experience motion sickness or/and motion induced anxiety. Arrangements have been made to accommodate a situation where these may occur. They can be seen in section 29 of the ethics application approval form.

5.6 Results

Table 5.1: Comparative study traditional class group results

Traditional Class Participant	NASA TLX Score
2	73.666
3	75.666
4	84.333
5	58

Mean: 72.9
Standard Deviation: 9.5

Table 5.2: Comparative study VR class group results

VR Participant	NASA TLX Score
6	61.665
7	84.666
8	33
9	43.666

Mean: 55.7
Standard Deviation: 19.6

Figure 5.3: VR SUS results

Participant	SUS Score
6	72.5
7	72.5
8	75
9	97.5

Mean: 79.4
Standard Deviation: 10.5

5.7 Discussion

The results from the comparative study suggests that there is a greater workload associated with the traditional class that lacks multimodal aspects. Judging from individual results of participants for the traditional class group, it can be suggested that the heavy weight tally associated with a high level of frustration resulted in a higher scoring. During the teaching of this class, the participants were asked three questions on the lesson topic and all three participants answered incorrectly. It is possible this caused the students to score frustration highly and score performance poorly. In relation to the dispersion of weights among titles, no participants for the traditional class group had weights associated with physical demand. This lack of spread could also be a possible reason for why frustration was scored highly.

In contrast to the traditional class group, frustration was not as heavily weighted in the VR group, as a total of five weights were counted for all four participants. While it was expected that using VR would have meant that a greater workload was expected, the participants generally found the system less frustrating to use. One possible reason for this was that when completing the interactive game, the students engaged in verbal communication with the teacher, as well as being encouraged to think back to particular sections of the lesson. Another possible reason for this was that each participant who took part in the VR class group has had previous experience with using a HMD. The standard deviation of the VR group is greater than that of the traditional class group, suggesting that the VR group offers a more unpredictable experience.

The results from the SUS questionnaire demonstrates that the VRLE is of high quality in relation to its usability. Each score calculated was above the average SUS score of 68. It must be noted that the participant's previous experience with VR technology could have influenced this. For example, for statement 10 (I needed to learn a lot of things before I could get going with this application), every participant chose 'strongly disagree'. If the user is assumed to be a complete novice with VR, this statement could have been scored differently. If testing was to be carried out again, it would be beneficial to seek participants who have no prior VR experience as this could give a greater indication of how usable the system is as a more inclusive population is being accounted for.

The two additional questions that were included in the SUS questionnaire were not included in calculating the results. This decision was made to ensure statistical validity. Referring to Appendix G, the scores for statements 11 and 12 vary for each participant. Participant six answered strongly disagree to both statements. As both statements positively equate with the usability of the system, this would be something that should be addressed if another prototype of the VRLE was to be made.

6 Future Works

6.1 Avatar Implementation

As the project was originally intended to be a collaborative space, research time was allocated towards avatars and virtual environments. Avatars are essential to social VR and their level of realism affects the user's "sense of presence, interpersonal interactions, and copresence" (Wu et al., 2021, p.1). The in which users communicate non-verbally in shared virtual spaces are determined by the effectiveness of their avatar implementation system.

The importance of avatars in SVEs (Shared Virtual Environments) can be seen in the work that has been carried out on using VR as an educational tool for children that have high-functioning ASD (Autism Spectrum Disorder) (Herrero et al., 2018). The implementation of avatars in such systems provides users with a more natural form of social communication than in systems without them. Previous work such as Sticher et al.'s (2013), VLE for young people with high-functioning ASD showed that avatars both helped the users feel immersed in the virtual world and they helped individuals learn emotion recognition through their representations. As usability is a core component of the VRLE proposed as part of this project, the inclusion of avatars would be beneficial so that students would feel more immersed in the environment and that high-functioning autistic students would be more appropriately accommodated for.

Wu et al.'s (2021, p.13) work on creating highly expressive avatars could be used as a foundation for the implementation of this into the project. They argue that VR avatar systems would benefit from the use of additional body-worn trackers that would lend to creating more highly-expressive avatars. Body tracking data was captured by Kinetic v2 devices, hand tracking was captured by a multi-LMC system and eye and mouth movement was captured by a HMD that had small adaptations made to it. Their study showed that this system in comparison to one that is low-expressive, provides the user with a higher sense of social presence and "improves task performance with a higher number of successful explained words".

If further time and hardware resources were available, a similar system should be developed and implemented into the VRLE. If the teacher (through the use of an avatar) was to guide students in the VRLE, they could utilise this system by making non-verbal communications as well as using the voice chat that has already been proposed. The general accessibility of the VRLE would be approved, as high functioning ASD students could benefit from enhanced social communication. However, one criticism that can be considered in relation to this is that people with ASD experience more "anxiety-related physiological activity in response to avatars' emotional displays" than people without ASD (Miller et al., 2016, p.251). Implementing highly expressive avatars means the VRLE could be potentially stressful for students who have ASD.

6.2 Haptics

Haptics can be described as a sensory memory system of the hands and arms that incorporates inputs from various sensory systems. These systems include skin, muscles and joints (Mills et al., 2022). Haptics have generally been difficult to accommodate in VR. While this has been the case, the absence of haptics does not hinder the production of high quality VR content (Johnson-Glenberg, 2018). The VRLE that has been proposed as part of this project does not feature haptic features. While some may argue that the absence of haptics from an application such as a VRLE may not be of significant attention, there has been work carried out in the area of VR and haptics that may be beneficial to this project.

The work of Mills et al. (2022, p.351) argues the case for haptics in VR. This can be seen in their proposed drawing tool for educational use. In the case of using their tool, they say that haptics is shown through "transformative touch". It is given this title because "hand and arm movements are instrumental in shaping semiotic material". This type of tool has the potential to be a fundamental part of a multimodal educational experience as it includes significant body movements and the "engagement of multiple senses" as part of the learning experience. In the case of the proposed VRLE, the drawing tool featured was simply a whiteboard that consisted of a 2D plane and a marker. While this was proposed to ensure the realism of the classroom, a tool such as the one discussed could be better in the context of multimodal learning. If time permitted, a 3D drawing tool that requires larger body movements than that of a 2D counterpart should be implemented into the project.

As well as haptic movements being a part of the project, there also is potential to include hardware that accommodate haptics in a VRLE. Specifically, the use of haptic gloves used in VR education can be looked at. Civelek & Fuhrmann (2022. p.33) note that sense gloves use vibrotactile feedback to create the feeling of touch. The use of these gloves with C# scripts developed for SteamVR allowed for "Force feedback, gripping, deformation, manipulation and tracking of the virtual objects" to occur.

Haptic gloves are beginning to be explored in virtual education settings such as piano lessons and VR labs. However, an area that would be of particular interest to this project is a virtual keyboard system that uses haptics. User tests show that keyboards in VREs that use haptic feedback outperform keyboards that don't in terms of realism and comfort of use (Wu et al., 2017). The VRLE that has been proposed did include any feature that would allow the students to take notes as it was purposefully chosen to not include any text based tools for the users to interact with as the project focuses more on other media streams. Despite this, the emergence of the use of haptic gloves in VR education shows strong potential. A tool such as a virtual keyboard would be of interest as it could allow students to take notes during the lesson in the classroom scene.

7 Conclusion

The goal of this project was to create a VRLE that primarily seeks to eliminate the lack of attention given to multimodality and usability in the construction of educational VR content. With regards to usability, this was accomplished by providing features such as an easy to use 2D UI menu and distance grabbable objects. To ensure the application's usability, user testing was carried out before having participants complete a SUS questionnaire and a NASA-TLX questionnaire, with the results showing that the project was successful in creating a system that upholds ease of use. With regards to multimodality, the final VRLE contained many different media sources that engaged with the user's senses. This includes images, an interactive game, audio sources etc. As well as accomplishing the goal stated here, the use of the VRLE to teach an interactive geography lesson based on a leaving cert question was something that had yet to be explored up until this point.

Despite the listed achievements, there are aspects of the VRLE that need to be revised. The failure to implement networking has to be addressed. If there was more time available to carry out prototyping, this is something that should be included as the classroom and desert biome were intended to be collaborative spaces. As well as this, more multimodal aspects should be featured. In particular, too little attention was given to haptics. If time permitted, haptic feedback for touching objects would have been implemented. For example, the controller could vibrate when the cacti are touched. Referring to the Future Works section, the use of haptic gloves would also be an interesting area to explore.

Usability testing was an essential part of this project. As stated above, it revealed how usable the VRLE was for participants. Under the 'Discussion' header in the 'Evaluation' section, various issues with the tests that were carried out were recognised. If there was more time available, this should be addressed. For example, in relation to the VR class group participants, there should have been a greater pool of people tested on who have different levels of familiarity with VR technology.

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Please note all other figures displayed in this work have been screenshotted directly from the APIs used to build this project.

Appendix C: Code Cited

Whiteboard.cs

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

public class Whiteboard : MonoBehaviour
{
    public Texture2D texture;
    public Vector2 textureSize = new Vector2(2048, 2048);
    // Start is called before the first frame update

    void Start()
    {
        var r = GetComponent<Renderer>();
        texture = new Texture2D((int)textureSize.x, (int)textureSize.y);
        r.material.mainTexture = texture;

    }
}
```

WhiteboardMarkerScript.cs

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

public class WhiteboardMarker : MonoBehaviour
{
    [SerializeField] private Transform _tip;
    [SerializeField] private int _penSize = 5;

    private Renderer _renderer;
    private Color[] _colors;
    private float _tipHeight;

    private RaycastHit _touch;
    private Whiteboard _whiteboard;
    private Vector2 _touchPos, _lastTouchPos;
    private bool _touchedLastFrame;
    private Quaternion _lastTouchRot;

    // Start is called before the first frame update
    void Start()
    {
        _renderer = _tip.GetComponent<Renderer>();
```

```
   _colors = Enumerable.Repeat(_renderer.material.color, _penSize *
   _penSize).ToArray();
   _tipHeight = _tip.localScale.y;
}

// Update is called once per frame
void Update()
{
   Draw();

}

private void Draw()
{
   if (Physics.Raycast(_tip.position, transform.up, out _touch, _tipHeight))
   {
      if (_touch.transform.CompareTag("Whiteboard"))
      {
         if (_whiteboard == null)
         {
            _whiteboard = _touch.transform.GetComponent<Whiteboard>();
         }

         _touchPos = new Vector2(_touch.textureCoord.x, _touch.textureCoord.y);

         var x = (int)(_touchPos.x * _whiteboard.textureSize.x - (_penSize / 2));
         var y = (int)(_touchPos.y * _whiteboard.textureSize.y - (_penSize / 2));

         if (y < 0 || y > _whiteboard.textureSize.y || x < 0 || x >
   _whiteboard.textureSize.x) return;

         if (_touchedLastFrame)
         {
            _whiteboard.texture.SetPixels(x, y, _penSize, _penSize, _colors);

            for (float f = 0.01f; f < 1.00f; f += 0.01f)
            {
               var lerpX = (int)Mathf.Lerp(_lastTouchPos.x, x, f);
               var lerpY = (int)Mathf.Lerp(_lastTouchPos.y, x, f);
               _whiteboard.texture.SetPixels(lerpX, lerpY, _penSize, _penSize,
   _colors);
            }

            transform.rotation = _lastTouchRot;

            _whiteboard.texture.Apply();
         }

         _lastTouchPos = new Vector2(x, y);
         _lastTouchRot = transform.rotation;
```

```
            _touchedLastFrame = true;
            return;
        }
    }

    _whiteboard = null;
    _touchedLastFrame = false;
  }
}
```

SceneSwitcher.cs

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

public class SceneSwitcher : MonoBehaviour
{
  public void playGame()
  {
    SceneManager.LoadScene(SceneManager.GetActiveScene().buildIndex + 1);
  }

  public void back()
  {
    SceneManager.LoadScene(SceneManager.GetActiveScene().buildIndex - 1);
  }
}
```

UIAppear.cs

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

public class UIAppear : MonoBehaviour
{
  [SerializeField] private Image customImage;

  void OnTriggerEnter(Collider other)
  {
    if (other.CompareTag("Player"))
    {
      customImage.enabled = true;
    }

  }
```

```
    void OnTriggerExit(Collider other)
    {
        if (other.CompareTag("Player"))
        {
            customImage.enabled = false;
        }
    }
}
```

SoundTrigger.cs

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

public class SoundTrigger : MonoBehaviour
{
    public AudioClip triggerSound;
    AudioSource audioSource;

    void Start()
    {
        audioSource = GetComponent<AudioSource>();
    }

    void Update()
    {

    }

    void OnTriggerEnter(Collider other)
    {
        if (triggerSound != null)
        {
            audioSource.PlayOneShot(triggerSound, 0.7F);
        }
    }
}
```

PlaySound.cs

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

public class PlaySound : MonoBehaviour
{
    public AudioClip SoundToPlay;
    public float Volume;
    AudioSource audio;
```

```
    public bool alreadyPlayed = false;
    void Start()
    {
        audio = GetComponent<AudioSource>();
    }

    void OnTriggerEnter()
    {
        if (!alreadyPlayed)
        {
            audio.PlayOneShot(SoundToPlay, Volume);
            alreadyPlayed = true;
        }
    }
}
```

StatementsVer.cs

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

public class StatementsVer : MonoBehaviour
{
    [SerializeField] private Image customImage;

    void OnTriggerEnter(Collider other)
    {
        if (other.CompareTag("STrue"))
        {
            customImage.enabled = true;
        }

    }

    void OnTriggerExit(Collider other)
    {
        if (other.CompareTag("STrue"))
        {
            customImage.enabled = false;
        }
    }
}
```

Appendix D: Project Assets

Arid Sand Image. Burke, B. brookeburkepicszar.blogspot.com/2021/08/sand-grass-earth-high-texture-arid.html
Classroom. PolyMarket369. https://www.cgtrader.com/3d-models/interior/other/classroom-068b4878-94d1-496f-ba23-9f9ee67c870a
ColorSkies. PULSAR BYTES. https://assetstore.unity.com/packages/2d/textures-materials/sky/colorskies-91541
Frown Face Image. Painting Valley. https://paintingvalley.com/happy-sad-face-drawing
IRONHEADGAMES Folder. IRONHEAD. https://ironheadvr.com/#
Leaving Cert. Geography (Higher) 2007: Part Two Q16 – 18. Examit. https://www.e-xamit.ie/tutorial.php?id=11847
Multiplayer Virtual Reality (VR) Development With Unity. Ufuk, T. & IRONHEAD Games. https://www.udemy.com/course/multiplayer-virtual-reality-vr-development-with-unity
Normcore Free - Multiplayer + Voice Chat for All Platforms. Normal. https://assetstore.unity.com/packages/tools/network/normcore-free-multiplayer-voice-chat-for-all-platforms-195224
Oculus Integration Package. Oculus. https://assetstore.unity.com/packages/tools/integration/oculus-integration-82022
Photon Voice 2. Photon Engine. https://assetstore.unity.com/packages/tools/audio/photon-voice-2-130518
POLYDESERT. Runemark Studio. https://assetstore.unity.com/packages/3d/environments/landscapes/polydesert-107196
PUN 2 - FREE. Photon Engine. https://assetstore.unity.com/packages/tools/network/pun-2-free-119922
Smiley Face Image. ClipArtBest. www.clipartbest.com/clipart-aie6b449T
SteamVR Plugin. Valve Corporation. https://assetstore.unity.com/packages/tools/integration/steamvr-plugin-32647
Triton. Milamila. https://www.turbosquid.com/3d-models/free-x-mode-triton/1042088

Please note all MP3 files were created using text2speech.org and all slide images were created using GIMP. Appendix D is sorted by asset name, creator name, followed by link to source.

Appendix E: Project Packages

Test Framework, Version 1.1.31. com.unity.test-framework
XR Plugin Management. Version 4.2.1. com.unity.xr.management
Timeline. Version 1.6.4. com.unity.timeline
Visual Studio Code Editor. Version 1.2.5. com.unity.ide.vscode
Visual Scripting. Version 1.7.8. com.unity.visualscripting
Version Control. Version 1.15.18. com.unity.collab-proxy
Unity UI. Version 1.0.0. com.unity.ugui
Visual Studio Editor. Version 2.0.16. com.unity.ide.visualstudio
Oculus XR Plugin. Version 3.0.2. com.unity.xr.oculus
TestMeshPro. Version 3.0.6. com.unity.textmeshpro
JetBrains Rider Editor. Version 3.0.15. com.unity.ide.rider

Appendix E is sorted by package name, version used, followed by link to source

Appendix F: Tutorials Followed

Barnett, J. P. (2021). *How to Create a Whiteboard in Unity VR - A Step-by-Step Guide* [Video]. Youtube. https://www.youtube.com/watch?v=sHE5ubsP-E8&ab_channel=JustinPBarnett

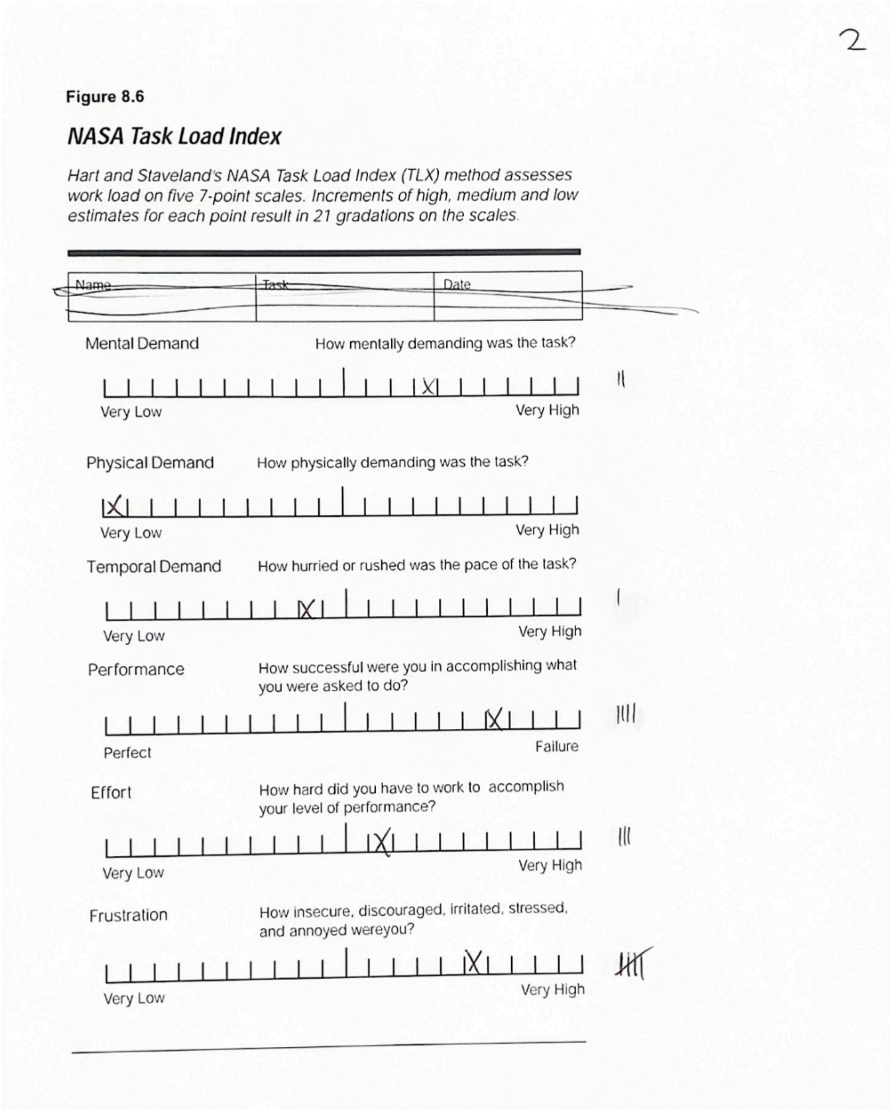
Heer. (2019). Unity – *How to Use a Button To Switch Between Scenes* [Video]. YouTube. https://www.youtube.com/watch?v=PpIkrff7bKU&t=78s&ab_channel=Heer

Lurony. (2016). *Unity 5 - How to Trigger Audio Only Once* [Video]. YouTube. https://www.youtube.com/watch?v=cXiVKPfNK1U&ab_channel=Lurony

SpeedTutor. (2017). *Image Appear on TRIGGER in Unity* [Video]. YouTube. https://www.youtube.com/watch?v=UVUMqss4A34&ab_channel=SpeedTutor

Appendix G: Evaluation Test Results

Traditional Class Group TLX



2

Figure 8.6

NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

~~Name~~	~~Task~~	~~Date~~

Mental Demand — How mentally demanding was the task?

Very Low — Very High — II

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High — I

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure — IIII

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High — III

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High — IIII

3

Figure 8.6

NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High

4

Figure 8.6

NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High

5

Figure 8.6

NASA Task Load Index

Hart and Staveland's NASA Task Load Index (TLX) method assesses work load on five 7-point scales. Increments of high, medium and low estimates for each point result in 21 gradations on the scales.

Name	Task	Date

Mental Demand — How mentally demanding was the task?

Very Low — Very High

Physical Demand — How physically demanding was the task?

Very Low — Very High

Temporal Demand — How hurried or rushed was the pace of the task?

Very Low — Very High

Performance — How successful were you in accomplishing what you were asked to do?

Perfect — Failure

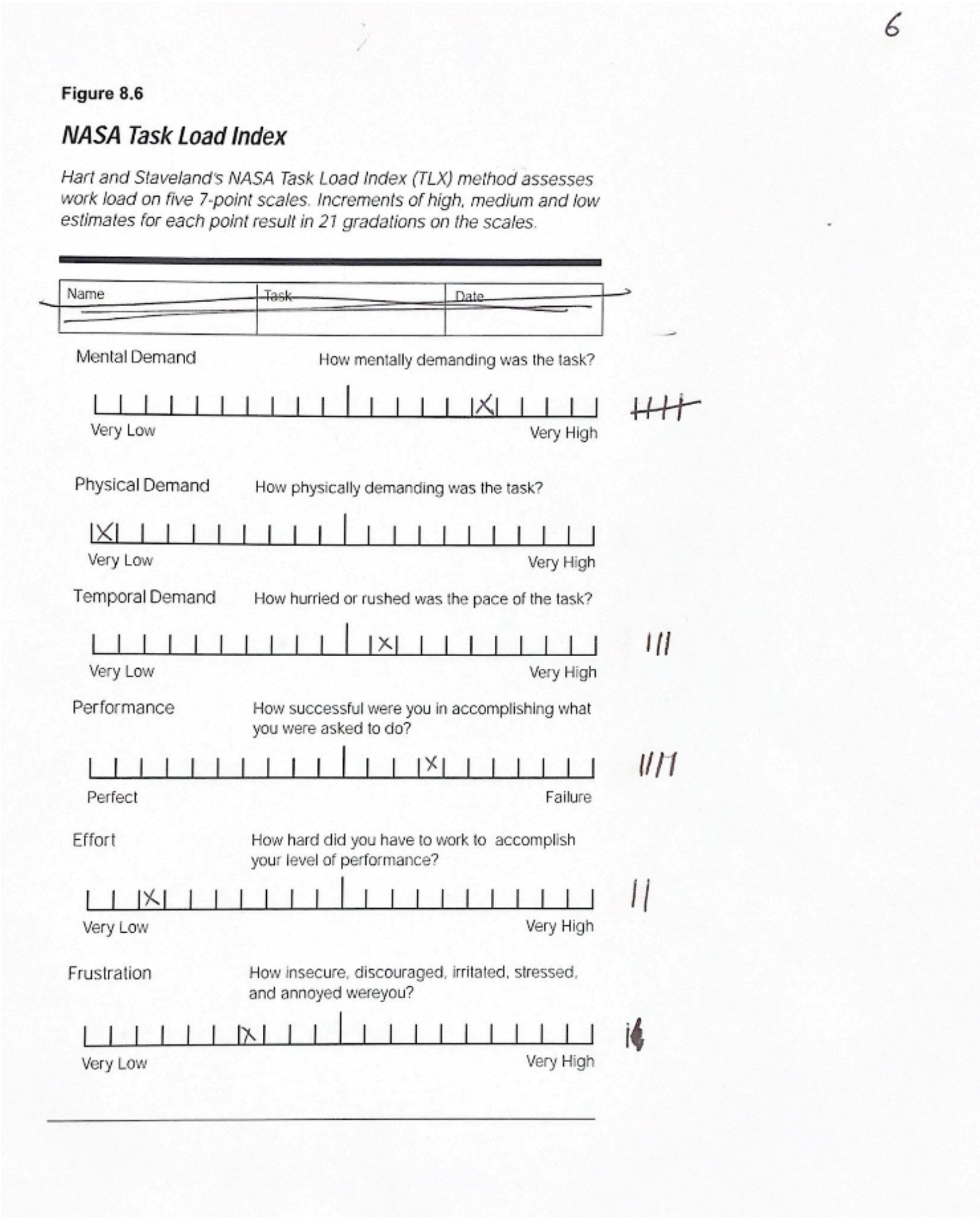
Effort — How hard did you have to work to accomplish your level of performance?

Very Low — Very High

Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High

VR Class Group TLX



6

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8

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Frustration — How insecure, discouraged, irritated, stressed, and annoyed wereyou?

Very Low — Very High

VR Group SUS

6

	Strongly Disagree				Strongly Agree
1. I think that I would like to use this application frequently	☐	☐	☐	☒	☐
2. I found the application unnecessarily complex	☐	☐	☒	☐	☐
3. I thought the application was easy to use	☐	☐	☒	☐	☐
4. I think that I would need the support of a technical person to be able to use this application	☐	☒	☐	☐	☐
5. I found the various functions in this application were well integrated	☐	☒	☐	☐	☐
6. I thought there was too much inconsistency in this application	☒	☐	☐	☐	☐
7. I would imagine that most people would learn to use this application very quickly	☐	☐	☐	☐	☒
8. I found the application very cumbersome to use	☐	☒	☐	☐	☐
9. I felt very confident using the application	☐	☐	☐	☒	☐
10. I needed to learn a lot of things before I could get going with this application	☒	☐	☐	☐	☐
11. I found that the content in the application was helpful in informing me of my current task	☐	☒	☐	☐	☐
12. I felt that I was able to continuously reuse techniques that I learned on previous tasks on my later tasks	☐	☒	☐	☐	☐

7

	Strongly Disagree				Strongly Agree
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2. I found the application unnecessarily complex	☑	☐	☐	☐	☐
3. I thought the application was easy to use	☐	☐	☐	☑	☐
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