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# Abstract

# Chapter 1 - Introduction

## 1.1 Introduction

Like a funnel – summarise the Context chapter headings – talk about the possible outcomes of this project. i.e. the plugin and the opportunities it presents for both people with and without learning disabilities.

While the expansiveness of possible explanations behind why some users find the VR experience uncomfortable

Despite the presence of numerous hardware solutions that are capable of effectively facilitating the simulation of walking, none are financially viable from the perspective of a user that would like the experience to be self-contained within their VR HMD and motion controllers.

## 1.2 Aims

The primary aim of this project is to demo a suitable set of Virtual Reality (VR) navigation paradigms through a VR1 study (Birckhead et al. 2019) that enables individuals with learning disabilities to navigate a virtual space with ease and comfort.

A subsequent aim of this project is to produce an open-source multiple navigation paradigm Unreal Engine plugin for distribution.

## 1.3 Objectives

* Examine and analyse the current Independent Travel Training process by reviewing the positive impact it has had and its current limitations.
* Investigate the current effectiveness of VR as a Travel Training tool through comprehensive research into Travel Training studies and the predecessors to this application.
* Develop and report on an in-depth understanding of the experiences of those with learning disabilities, especially regarding independent travel.
* Prototype a VR application that aligns with existing research and includes new ideas on navigation paradigms to create a useful tool that can be used by people with learning disabilities to build up their independent travel confidence.
* Solicit travel training expert feedback on the application prototype to inform the implementation phase of the next stage prototype.
* Conduct research and testing ethically, legally, and professionally in compliance with the British Computing Society’s (BCS) Code of Conduct.
* Document and report on the findings of this project in a detailed and comprehensive manner so that it may be used to supplement the understanding of interaction paradigms and locomotion in future research.

# Chapter 2 - Context

## 2.1 Virtual Reality for People with Learning Disabilities

In addition to Virtual Reality’s (VR) role in treating and educating individuals without learning disabilities (Mantovani et al. 2004; Van Wyk, De Villiers 2009; Aïm et al. 2016), applications of VR in this context can also be seen in studies on neurodivergent individuals with phobias (Coelho et al. 2009), autism (Welch et al. 2009; Strickland et al. 1996) and traumatic brain injuries (Mondello et al. 2018).

This is in part due to VR’s ability to model the real world in a safer and more controlled manner (Standen, Brown 2005). Moreover, studies (Brooks et al. 2002; Rose et al. 2002; Standen, Brown 2005; Daniela et al. 2022) investigating the efficacy of VR in training people with learning disabilities found that participants “enjoyed the experience” and that for certain task scenarios “virtual training and real training were found to be equivalent” in effectiveness (Brooks et al. 2002, p.625). The virtual learning environment (VLE) allows the user to repetitively simulate the same scenario as many times as they need without the influence of extraneous variables.

## 2.2 Virtual Reality in Travel Training

Independent Travel Training is another example of an area where VR has begun to thrive in its application. Travel training is a form of therapy for individuals with learning disabilities to help them achieve independence concerning unaccompanied travel. The effectiveness of VR in this area has found that it can lead to more confidence (Bernardes et al. 2015) with independent travel and that it can also significantly reduce electrodermal activity (metric for anxiety) (Simões et al. 2018).

The findings from the predecessors to this project echo similar conclusions in favour of VR’s effectiveness as a travel training tool for individuals with learning disabilities. To expand upon the existing understanding of VR’s efficacy in this area, a review of relevant publications has revealed a reoccurring theme surrounding navigation and interaction paradigms.

### 2.2.1 Navigation and Interaction Paradigms

Through a review of 8 relevant publications, it can be inferred that navigation methods and interaction paradigms for individuals with learning disabilities are often under-reported or under-researched. This is especially prominent in the case of full immersion into the virtual environment wherein a keyboard and mouse are no longer feasible options for navigation due to the use of a head mounted display (HMD) blocking their view.

For non-immersive environments, there seem to be conflicting views on whether the keyboard and mouse or joysticks are the ideal method for navigation. The results of one study (Standen et al. 2006) found that in “the vertical plane only” the use of a mouse resulted in “better performance” compared to the joystick, but the joystick did perform better when compared to “arrows on the keyboard” as it “enabled participants to gain consistently higher scores” (Standen et al. 2006, p.612).

On the other hand, another study (Brown et al. 2002) found that most participants struggled to use a keyboard and mouse to navigate the virtual world with one participant finding “keyboard control very difficult” (Brown et al. 2002, p.186). A potential solution to this was identified via the joystick in which one participant had “almost instant success” (Brown et al. 2002, p.186) while using it on the Zebra crossing level. Through a review of user feedback from both studies, it can be surmised that the conflicting opinions are partly influenced by differing user preferences.

Similarly, immersive environment-based studies (Checa et al. in Lucio Tommaso De Paolis, Patrick Bourdot 2019; Cobbs et al. in Sharkey et al. 1998; Shopland et al. 2004) discuss the difficulties participants had with the interaction paradigms surrounding joystick-based navigation and player point of views (POVs) in the virtual learning environments (VLEs). While these studies did not pursue an investigation into locomotion methods, questionnaire answers revealed relevant contradictory findings. Despite navigation being reportedly “one of the most difficult tasks to do” it was often indicated to be the “most enjoyable aspect” (Cobbs et al. in Sharkey et al. 1998, p.19) when using the VLE. This raises the question of whether navigation paradigms are capable of being described as both enjoyable experiences and easy to use. Alternatively, the findings also present the possibility that for the paradigm to be perceived as enjoyable to use, it must present the user with a degree of complexity regarding its usage. From the perspective of implementing navigation paradigms for individual with learning disabilities, it may be more beneficial to implement a solution that caters to both criteria.

The remaining studies (Strickland et al. 1996; Simões et al. 2018; Bernardes et al. 2015) briefly describe their navigation paradigms, however, they do not provide an evaluation or additional comments surrounding the user’s experience with navigation and locomotion within the virtual world.

Conversely, studies (Langbehn et al. 2018; Tanaka et al. 2020; Cherni et al. 2020; Freiwald et al. 2022) investigating locomotion and navigation paradigms in VR with people without learning disabilities have discussed the impact different paradigms have on user experience. The literature review by Cherni et al. takes it a step further by categorising the different paradigms using their proposed taxonomy. Yet, as the studies’ findings are based on samples of individuals without learning disabilities, the conclusions drawn from them cannot be generalised to the VR travel training context. Moreover, the studies do not report on the ways in which the interaction paradigms may need to be modified to suit the needs of an individual with learning disabilities.

This presents a gap in research where a pilot study would be beneficial. The study would use user-centred design and consist of the implementation of various navigation paradigms to assess them based on ease of use, realistic movement, and user experience. The study's findings would form the foundation for future work on navigation and interaction paradigms for individuals with learning disabilities.

## 2.3 Discomfort and User Experience

While ease of use and realistic movement are pivotal factors in determining whether a navigation paradigm is suitable for use in the project’s context, it does not encapsulate the entire user experience. Hence, to thoroughly assess the efficacy of a paradigm, one additional factor needs to be considered, user experience on the basis of comfort.

Motion sickness or otherwise known as cybersickness, simulator sickness or virtual reality sickness has long been an area of discussion concerning user experience in VR. The article by Chang et al. notes that there are a few different causes of motion sickness in a VR application. These can be broken down into three main categories: “hardware”, “human factors” and “content” (Chang et al. 2020, p.1660).

### 2.3.1 Hardware

From a hardware perspective, it is believed that motion sickness can be brought about due to factors such as display type and mode (Harvey, Howarth 2007), hardware field of view (FOV) (Seay et al. 2001), latency (DiZio and Lackner 1997 in Chang et al. 2020; Bronstein et al. 2020), and flickering (Renkewitz, Alexander 2007). As interest in VR experiences continues to grow significantly (Dluhopolskyi et al. 2021), there is now a need to overcome these issues “to allow broader people” access to “enjoy VR in their daily lives” (Chang et al. 2020, p.1660). Recent technological advancements and research have facilitated the development of a variety of different solutions (Pohl et al. 2013; van Waveren 2016; Nguyen 2020; Kumar Kundu et al. 2021); some of which now come as part of the consumer-grade HMD devices available to the public.

One such solution is the implementation of Asynchronous TimeWarp (ATW) within the Meta Quest 2 HMD (Meta 2020). The TimeWarp technique works by warping a rendered image before it is sent to the display. This is done to account for head motion that occurs once a scene is rendered, thus, reducing the perceived latency (Michael Antonov, Meta 2015). The asynchronous version of this simply handles the warp on another thread that runs in parallel with rendering. Another solution involves reducing the hardware FOV as it was found to alleviate discomfort in users. In Y. Y. Kim’s implementation, a detection system was designed to detect ‘biosignal’ feedback and respond accordingly by reducing the field of view; the method is called the Cybersickness Relief Virtual Environment (CRVE). The study reported lower cybersickness levels for participants in the CRVE condition compared to those in the non-CRVE condition (Kim et al. 2008). Finally, modular latency or HMD refresh rates is a solution that’s both accessible to the user and VR developers. Within the Meta app, users can pick from a range of different refresh rates (i.e., 60Hz to 120Hz) while a developer can set the desired refresh rate of their app via their development tools (i.e., Unreal Engine).

Based on the studies discussed above, hardware is an area that’s been thoroughly investigated. Moreover, as has been established in the analysis of existing solutions, most of these have been integrated into present-day HMD devices or are in the process of being implemented. Thus, there is no need to further investigate hardware as a cause for motion sickness and discomfort in relation to this project.

### 2.3.2 Human Factors

Human factors are another area that can potentially impact a user’s level of comfort within a VLE. Studies (Stanney et al. 2016; Chang et al. 2020; Saredakis et al. 2020) have found that factors such as gender and age can potentially have a considerable impact on cybersickness though others (Melo et al. 2021) argue that there is insufficient evidence. In a review of studies **(ref here)** that investigate the influence of age, findings returned mixed results. Results of studies **(ref here)** on gender echo a similar sentiment. **(Include data)** Thus, it is still difficult to conclude whether these factors influence a user’s level of comfort in VR despite having a few different studies looking to quantify them as factors.

Learning disabilities as a human factor, however, are still underreported, especially when compared to the factors discussed above. The studies (Wang, Reid 2011; Bian et al. 2013; Glaser et al. 2022) that are currently available do touch upon concerns surrounding the relationship between learning disabilities and motion sickness but there is a lack of quantifiable data available. Based on existing research into vestibular dysfunction in adults with autism (Stankiewicz et al. 2020) it can be theorised that individuals with autism might be more susceptible to experiencing cybersickness in the virtual world because of ocular vestibular mismatch.

### 2.3.3 Content

There are a variety of different content elements that have been found to contribute to cyber sickness. This includes optical flow (Bonato et al. 2008; Keshavarz, Hecht 2011; Lubeck et al. 2015), controllability (Jaeger, Mourant 2001; Dong, Stoffregen 2010; Chen et al. 2011), graphic realism (Golding et al. 2012; Davis et al. 2015; Carnegie, Rhee 2015), and content FOV (Fernandes, Feiner 2016; Kobayashi et al. 2015).

#### Content FOV

As outlined in the hardware discussion, the FOV plays a role in influencing a player’s level of discomfort within the virtual world. Another method of modifying the FOV is through the content. In two studies (Kobayashi et al. 2015; Fernandes, Feiner 2016) both concluded that narrowing the FOV via content was also an effective method of reducing a user’s VR sickness symptoms. However, as this is out of the scope of the project, content FOV modifications will need to be investigated further in future work to determine its potential role as a motion sickness content factor.

#### Graphic Realism

Graphic realism is another content factor that has been thoroughly investigated to reduce user discomfort. However, contrary to what was expected, the studies found that improved graphics and degree of realism in the virtual environments did not lead to reduced reporting of cybersickness (Golding et al. 2012; Davis et al. 2015; Carnegie, Rhee 2015). Chang et al. suggest that this may be due to the “sensory discrepancy” between “visual and vestibular information” (Chang et al. 2020, p.1669) that relate to other content factors such as optical flow and controllability.

As this project is building upon the foundations of its predecessors it will include revised 3D models and textures that represent technological developments over the years that have allowed for an overall improvement in the quality of the VLE. It will not, however, investigate in-depth the relationship between graphic realism and user discomfort. Instead, the project will look towards examining the successfulness of the navigation paradigm implementations derived from an understanding of the remaining content factors discussed below.

#### Controllability

Controllability as a content factor can be divided into two categories, passive and active experiences. Passive navigation in a virtual world typically limits the user’s interactions and has been found to be the cause of motion sickness (Jaeger, Mourant 2001). It was also concluded that a user’s experience would become worse when controllability was lost, and they were forced to experience the virtual environment passively (Chen et al. 2011; Dong, Stoffregen 2010). Thus, this emphasises the need for well-designed interaction paradigms that keep the user engaged and comfortable throughout the experience. From the perspective of the project’s application, this relates to its use of navigation paradigms to teach the user good road-crossing habits. This can be implemented using the VR motion controllers and HMD as trackers for a player’s movement and gestures, thus, encouraging them to actively move about and interact with the VLE. Moreover, by having the user interact with the virtual world to navigate within it, the user simulates real-world behaviours (i.e., walking and crossing roads) that are required as part of the learning experience of the travel training simulation.

#### Optical Flow

The final content factor is optical flow; it has been observed that humans are more likely to become nauseous when they see moving content than static content (Bonato et al. 2008; Lubeck et al. 2015). A potential reason for this is that “moving stimuli produces the optical flow of a VR scene” thus enabling the user to “experience illusionary self-motion”. (Chang et al. 2020, p.1668). Speed has been noted to be a potential parameter that can influence the optical flow of a VR scene. In the study by Lo et al., it was determined that navigational speed can influence a user’s level of discomfort in VR wherein when speeds were raised from 3 m/s to 10 m/s it resulted in increased reporting of nausea. However, it was also noted that if the speed of the VR speed was too high, a user’s level of discomfort might not be as severe due to a reduced sense of presence (Lo, So 2001). The findings of Lu et al. echo this; when attempting to determine an interaction method to alleviate cybersickness, the study found that participants “are extremely sensitive to speed in VR” (Lu, Mao 2021, p.369). In addition to this, user feedback highlighted the need for a controllable speed as it was believed it might improve their comfort levels and reduce vertigo. From the perspective of the study, having locomotion paradigms with controllable speeds as a design decision might benefit the application’s users as they can adjust the speed of their player character to a degree that’s far more comfortable for them to experience.

The other parameter of optical flow involves rotational movements. Studies (Bonato et al. 2009; Keshavarz, Hecht 2011)found that users show a higher level of discomfort when subjected to rotational movements in comparison to translational movements. This feeling of discomfort is further exacerbated when the user is exposed to rotational movement across multiple axes (Bonato et al. 2009). This parameter further amplifies the occurrence of ocular vestibular mismatch (Bos et al. 2008) based on the conflicting stimuli a user receives from the real and virtual world. A solution to this from the perspective of the project is to limit these rotational movements in the VLE. Instead, any rotation of the player’s point of view is strictly produced in correlation with the HMD tracking data. Any movement of their head in the real world will be translated into the virtual world thus preventing them from experiencing the rotational movements that are expected or from a counter-intuitive angle.

Another method that incorporates both the speed and rotational movement parameters would be to implement a modified version of ‘out-of-body’ locomotion methods such as “holoport” and “ghosting” (VRChat 2016; Griffin, Folmer 2019). Instead of watching a player character walk to the point in the third person and then resuming the first-person perspective once at the endpoint, the modification would have the person ‘walk’ to the point from the first-person perspective with their HMD allowing them to rotate their head freely as their character moves to the endpoint.

## 2.4 User-Centred Design

User-centred design and the inclusion of users as “co-designers” takes advantage of how they are “experts by experience” (Harris et al. 2022, p.218). This experience can be used to facilitate the design and development of prototypes that are more in line with user needs (Gabbard et al. 1999; Barbieri et al. 2018).

To thoroughly capture and evaluate user experiences surrounding the navigation paradigms, the project will employ the use of feedback from travel training experts and individuals with learning disabilities via UCD methods (Spencer González et al. 2020; Bayor et al. 2021; Harris et al. 2022) such as interviews and focus groups.

The interviews and focus groups will look to solicit feedback that will influence design decisions made in the subsequent implementation phase.

These sessions will include an application demonstration which will be an opportunity for the target user group to trial the prototype and provide user experience feedback on the application. The questions will have a particular emphasis on how different navigation paradigms made users feel and what their preferences might be and why. This is so that the project can analyse and discuss in more depth the influence certain paradigms have on the user experience of people with learning disabilities. Moreover, observations made during the session will be noted and will also be utilised during the development of the subsequent prototypes.

The final prototype will include the necessary changes derived from the feedback sessions as well as all the minimum viable product (MVP) features outlined during the requirements gathering stage. This prototype will be trialled by a group of young adults without learning disabilities during preliminary testing as a means of assessing the efficacy of the developed testing protocol and obtaining baseline data on the overall success of the implemented solutions.

These findings of the pilot study can then be used to supplement future work involving a long-term investigation into a user’s preferred locomotion paradigm and the reported levels of discomfort via motion sickness as assessed by a Simulator Sickness Questionnaire (SSQ) (Kennedy et al. 1993) or VR Sickness Questionnaire (VRSQ) (Kim et al. 2018).

# Chapter 3 - New ideas

## 3.1 Application Design

To design an application that excels across the following categories: ease of use, user experience and realistic movement, the application must utilise the relevant content factors as design decisions. This pilot study will only focus on the optical flow and controllability factors discussed below to ensure the scope of the project isn’t exceeded.

### 3.1.1 Controllability

The project intends to create a training VLE that simulates the experience of crossing roads; therefore, the user should remain engaged by the content throughout the travel training process. Ideally, the game would provide the user with active experiences so that user engagement and comfortability are maintained. In previous iterations of the project, active experiences have been implemented using first-person perspectives in addition to the use of VR HMDs to deliver the VLE. Another solution would be to utilise the user’s real-world movements and gestures to simulate in-game actions which in the application’s context would be primarily for player locomotion. There is, however, a limitation to this in which the application needs to deliver its VLE within spaces that don’t necessarily have enough area to allow for free roaming.

There are a few different existing solutions that are known to successfully translate a player’s physical walking movements into virtual locomotion using limited space. These solutions include items such as linear and omnidirectional treadmills **[ref here]**. These treadmills allow the user to experience the same locomotion in the real world as they would in the VLE, thus, potentially reducing the impact of user discomfort factors. The omnidirectional treadmills with the full range of motion (360 degrees) provide a user with the ability to both walk and rotate themselves in any given direction without the need for an additional player rotation controller. While this is an interesting solution, it is, however, not portable. Moreover, most implementations of omnidirectional treadmills have yet to be made widely available to the consumer market.

On the other hand, Cybershoes (Cybershoes 2022) are a portable alternative that is available to the everyday VR user. These shoes allow the user to simulate locomotion from a seated position, and it captures rotation through the rotation of the user’s seat. Despite their portability and much cheaper price tag in comparison to the treadmills, it is still a financially unviable option.

To design an application that’s accessible to a wider user group, the VLE needs to utilise affordable solutions; hence the need for in-built content-based locomotion paradigms. As a result, controllability will be explored through the passive and active user experiences implemented within the paradigms. These physical existing solutions, instead, can be utilised in future work as comparison factors when attempting to quantify the efficacy of the paradigms as a means of determining the most suitable method for the application from a controllability perspective.

### 3.1.2 Optical Flow

In most VR games and simulations, teleportation has become the preferred mode of locomotion. Within the application’s context, however, this paradigm defeats the application’s primary learning objective which is to be a travel training tool that gets the users to mimic real-world behaviours via the VLE. Moreover, unless optimised beyond a standard implementation, it has the potential to disorient users by impairing their spatial awareness (Weibker et al. 2018). Hence, there is a need for alternative solutions that present the user with more realistic locomotion. To achieve this, speed and rotational movement as parameters need to be considered when implementing the paradigms. Both parameters influence how optical flow impacts a user’s comfort level in a virtual environment.

One existing optical flow solution can be seen in how VRChat which utilises a modified version of teleportation known as “holoporting” (VRChat 2016). The user watches their player character navigate to the selected endpoint from the third person before then being teleported to this new location. A more relevant implementation of this for this project would be to implement a similar version that utilises the first-person perspective instead. This concept is further explored in the discussion on the walk-to-point navigation method.

Another way in which speed as a parameter can be utilised is through implementing it as a modular, user-controlled variable. Providing the user with the flexibility to control how quickly they experience locomotion within the VLE has the potential to reduce vertigo and other negative side effects of motion sickness. This could be done using a pop-up wrist menu that the user interacts with.

## 3.2 Primary Interaction Paradigm Features

Based on the design factors discussed above, this application will include the implementation of five navigation paradigms that’ll be tested via the project’s user group. In addition to this, the application will also include revised versions of the different road crossing levels and their relevant assets.

### 3.2.1 Thumb-stick Navigation

Despite previous iterations of a similar implementation using a joystick garnering feedback that reported increased levels of discomfort via motion sickness, thumb-stick navigation has the potential to become a feasible navigation paradigm through a slight design modification.

For its implementation, this paradigm would utilise the axis of thumb-stick movement to dictate the back-and-forth and side-to-side player movement. The degree of linear tilt along the X and Y axis would influence the speed. As for the modification, the paradigm would use the flexible player speed feature discussed in Section 3.3.1 which may potentially generate differing user feedback surrounding discomfort and motion sickness.

### 3.2.2 Jogging in Place Navigation

**[ Insert Stuff here ] – Active experience**

### 3.2.3 Teleportation Navigation

While teleportation’s noncontinuous navigation approach has shown to cause significantly less nausea (Buttussi, Chittaro 2021), it is not a form of realistic movement from the travel training perspective as it does not allow the user to observe the travel route. In addition to this, teleportation can be deemed to be a relatively passive experience from a controllability perspective. As a result, it’s implementation in this project is primarily for the purpose of utilising it as a baseline for comparison against the other proposed paradigms.

Moreover, the programming logic behind this paradigm will be used as the groundwork for the walk-to-point implementation as both methods share a similar foundation with only slight variances in how the locomotion is presented to the user.

### 3.2.4 Walk-to-Point Navigation

A potential modification to the noncontinuous teleportation method is using it to facilitate the continuous ‘Walk to Point’ functionality instead. This concept utilises similar existing implementations wherein during the act of teleporting, a user can view a ghost of themselves moving to the endpoint (VRChat 2016). Similarly, in this new implementation, the user can use the teleportation tool to select a point they’d like to navigate to. Once selected, the player will begin to walk in that direction. Instead of seeing a ghost of oneself from a third-person perspective, the HMD would allow for free movement of the head to look in any direction from a first-person POV as the player's body moves towards the selected destination. This method as a locomotion paradigm would work quite well with static targets (i.e., crossing the road to reach the endpoint).

Challenges of using this method might arise when the user needs to follow a dynamic target (i.e., an NPC guide as they navigate roads). The process of selecting a target to walk towards could be too distracting, thus, resulting in the user ignoring active hazards in their surroundings. Hence, this highlights the need for additional alternative paradigms to be developed.

### 3.2.5 Arm-Swinging Navigation

The final navigation paradigm that will be implemented is arm-swinging. This would employ the use of arm-swinging gestures as a means of capturing locomotion input. Through the physical gestures, the paradigm, similar to the jogging in place method, would also utilise an active user experience while still staying within the limited space boundary. Moreover, it would provide users with an alternative navigation method, especially for users that might not be as experienced with controllers and buttons.

The downside of the method is the ambiguity behind the acceleration and deceleration mechanics being a potential disruptor to the optical flow of the scene as it is difficult to determine at what point during the arm swing the user would like to begin deceleration. Modification of this paradigm might involve the use of a formula to calculate the rate at which the arm swinging changes to determine whether the player’s speed is accelerating or decelerating. Another potential issue of the method if determining when a user’s movement of the arms is meant to trigger movement and of when it is meant to cause some other world related interaction. A proposed solution to this would be to use an additional checking mechanism that in the case the specified criteria is fulfilled, only then will the application compute the arm swing gesture as locomotion input.

## 3.3 Additional Paradigm Modifications

### 3.3.1 Modular Player Speed

A supplementary modification to all three navigation paradigms will include the ability to change one’s maximum locomotion speed as it could potentially reduce the influence of vertigo (Lu, Mao 2021). The customisable maximum speed might be more favourable for some users as it could lead to them feeling their in-game speed is more representative of their actual walking speed. Moreover, if a user feels that their speed in the VLE is what’s causing them to feel discomfort while they’re within a level, the application can offer them the flexibility to change their speed whenever they need to.

The user’s speed within the VLE will increase till it reaches the maximum depending on their chosen navigation paradigm and decelerate when they either get closer to their endpoint or indicate via the tracking metrics that they’re slowing down.

### 3.3.2 Application Levels

As the application is being designed to investigate the efficacy of different navigation paradigms within a travel training context, the map used to deliver the content will include a standard zebra crossing scenario wherein a player will have a target endpoint with a visualiser to navigate to. The level will also include moving vehicles to simulate a real-world crossing experience to add to the immersion of the level.

The application’s main menu will include a list of different navigation paradigms for the user to choose from. Upon selection, they will be then taken to the crossing level.

# Chapter 4 – Implementation

## 4.1 Introduction

The implementation stage of the project was broken down into several distinct phases: the planning phase, the prototyping phase, and the feedback phase. As outlined in the following section, a core trait of the agile methodology is that it supports an incremental, flexible process wherein system modifications are made in response to new information or requirements.

Hence, upon the completion of the planning phase, an iterative cycle of application implementation and feedback gathering would begin. The successful integration of a major feature into the VR application would mark the point at which feedback was needed. Interviews and demonstrations were conducted with travel training experts to collate enough information to inform the decisions behind the next prototype’s development.

## 4.2 Methodology

The implementation of this software will utilise the Scrum model of Agile methodology **[REF HERE?]**. The methodology was chosen as it provides the project with a high level of flexibility to respond to feedback obtained throughout the implementation and testing phases **[REF?]**. The Scrum model allows for an “incremental process” of development that gives way to “system flexibility” in a “constantly changing environment” (Awad 2005, p.10). In the context of this project that would be the need for software requirement changes as a result of factors such as bugs found during testing or feedback from the focus group.

The model’s key feature is the use of sprints; a set block of time within the overall project duration wherein planning, implementation, testing and reviews take place (Srivastava et al. 2017). At the end of each sprint is the opportunity to revise feature priority and update the next sprint’s plan. This frequent build and testing procedure aligns itself with good VR development practice. VR development requires that the software is packaged and deployed to the HMD often otherwise the developer runs the risk of finding major problems and bugs much later in production. Frequently deploying and testing on the HMD itself after the implementation of each feature ensures that any issue with the feature itself is identified early and scheduled to be resolved in the following sprint.

Outlined and analysed in Appendix **[]** and **[]**, each requirement of the project has been broken down and ranked in order of priority. An item’s priority is determined by its importance to the project and the predicted implementation difficulty level. In addition to this, the estimated time for completion was also considered when determining priority. This ranked list was then used to create the project’s Gantt chart in Appendix **[]**. The requirements, project milestones and other external commitments have been put together to form the overall project’s timeline. The chart includes several sprints for the different requirements with each including a planning, building, and testing stage followed by a review of progress before the start of the next sprint. Finally, to ensure all the project’s risks were accounted for with an appropriate mitigation plan in place, a thorough analysis was conducted and documented in Appendix **[]**.

## 4.3 Prototype Phase 1 – Implementation of Navigation Paradigms

### 4.3.1 Pawn and Character Classes

During the early stages of development, challenges began to arise due to the lack of flexibility that comes from the Pawn blueprint class when compared to the Character blueprint class as the pawn class does not come with the character movement component.

Thus, this makes it difficult to implement the modular variables option for a user to control their speed. Hence, to achieve a similar effect, one would need to implement this component from the ground up which would take a considerable amount of time. This resulted in the decision to swap over from a pawn to a character blueprint class and begin implementing the essential features needed for each paradigm.

This significantly improved the implementation process of the different locomotion paradigms as Unreal Engine’s pre-built functions like set velocity, set speed, and move to location could be called without the need to develop a separate, unique set of functions. Moreover, this decision provided a better development framework for the later implementation of collision detection based on user-feedback as outlined in the third prototype’s implementation section.

### 4.3.2 Thumb-stick Navigation

Thumb-stick navigation is one of the simpler paradigms to implement as it utilises the degree of thumb-stick tilt along the X and Y-axis to determine the direction and speed at which the user moves. The blueprint implementation of this paradigm compares the derived axis value against a ‘dead zone’ to first determine whether the magnitude is enough to propel the player in any given direction. In the case that it is, this axis value is multiplied by the user’s speed variable which is a modifiable value that can be changed via the user’s wrist menu. This product is then put through the inbuilt ‘add movement input’ function alongside a directional vector derived from the player’s camera.

Graphical user interface, application

Description automatically generated

Figure 1: Thumb-stick Navigation Blueprint

In the early stages of the development of this paradigm, speed as a variable could not be included as the blueprint was under the pawn class and thus, was restricted in how it could utilise the variable. The switch to the character class, as discussed in the section above enabled the integration of the modular speed variable so that the user has control of how fast they navigate the space with the paradigm they’ve selected.

### 4.3.3 Jogging in Place Navigation

To mimic a more natural form of movement, this paradigm utilises the motion detection feature of the HMD as a means of translating real-world movements into virtual momentum. Using an event tick, the blueprint frequently samples and checks for variances (within a threshold) in the HMD’s positioning. In the case that it’s surpassed this threshold, it then triggers the following logic to propel the user’s character forward using a series of calculations to determine the velocity and direction of movement.

A screenshot of a video game

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Figure 2: Jogging Navigation Blueprint

The structure of the blueprint also accounts for drastic fluctuations in the positioning variations. In the case that the fluctuations are more frequent and at a higher degree, the velocity of the user in the VLE when propelled forward increases. Similarly, it decreases in the case of less frequent and low-degree fluctuations.

The running multiplier and threshold are set to be modular parameters that can be modified via the user’s wrist menu in case these values need to be altered to better suit the user’s jogging style.

### 4.3.4 Teleportation Navigation

As this paradigm

### 4.3.5 Walk-to-Point Navigation

The baseline framework for this paradigm is derived from an implementation of a teleportation. Like the teleportation method, the user can draw an ‘arc’ to their desired location. This arc comprises all the points that lead up to the end point from their current location. In the walk-to-point blueprint, the endpoint is fed into the inbuilt ‘simple move to location’ function once the motion controller trigger is released, indicating the player’s wish to travel to this location.

A screenshot of a video game

Description automatically generated

Figure 3: Walk to Point Navigation Blueprint

The paradigm is designed with several different modular variables which include a character speed variable and a variable that dictates the range at which a user’s selection arc can reach from their current location. To ensure an area is suitable for this navigation, the map utilises a ‘NavMeshBounds’ volume. As can be seen in the diagram below, the space on the ground that’s highlighted in green is an area that a player is capable of navigating. All out-of-bounds locations will utilise a similar mechanism that blocks player navigation.

A picture containing sky, green

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Figure 4: Navigation area in a level

### 4.3.6 Arm Swinging Navigation

The arm-swinging method, similar to jogging in place, is a paradigm that aims to simulate a user’s VR movement using real-world natural, physical movements. In the project’s previous iteration, the arm-swinging paradigm would propel a user forward whenever they swung their arms. This posed a problem as the code didn’t account for the scenario wherein the user might need to make gestures with their arms without the intention of moving forward (i.e., pressing the button at a crossing or standing still and moving their arms).

A solution to this was to only fire the arm-swinging locomotion logic once a particular button on the motion controller was pressed. In line with the intention to mimic more natural movements, the decision was made to utilise the motion controller’s grip buttons for this as it emulated the gesture of one having closed fists while walking.

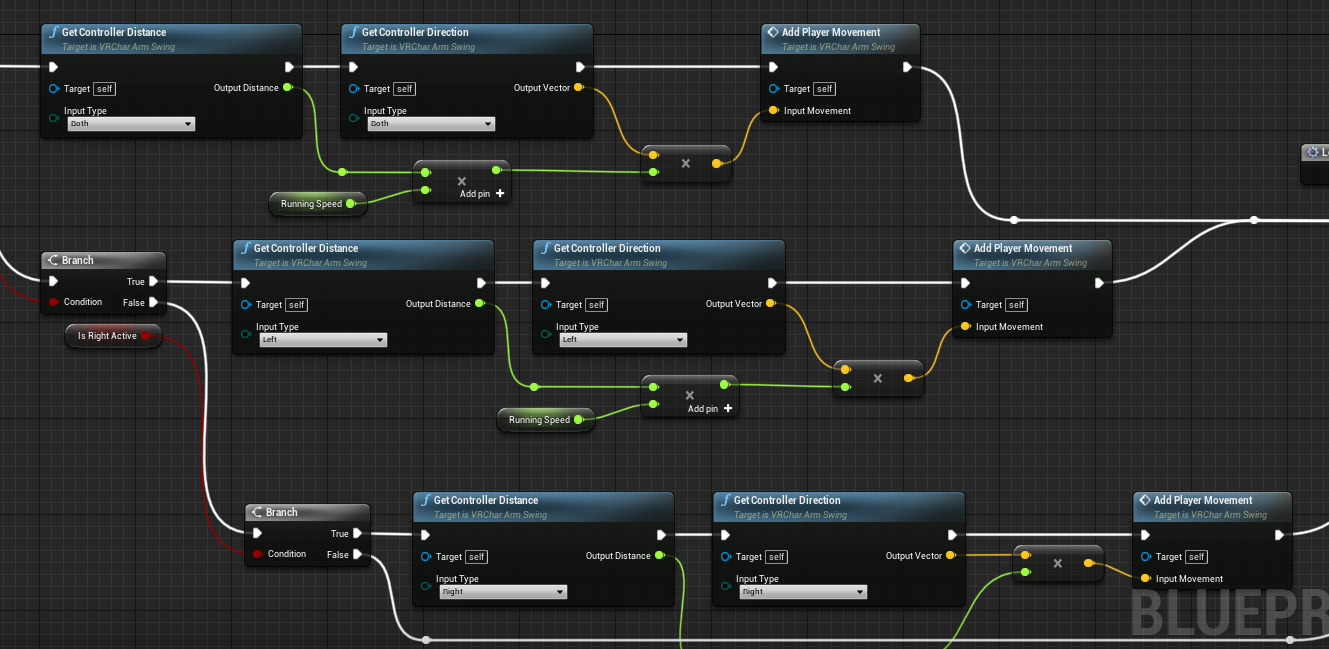


Figure 5: Arm Swinging Navigation Blueprint

The overall locomotion logic is broken down into three core functions, the first being to get the controller distance while it’s swinging to determine the rate at which the user is swinging their controller back and forth as a means of converting this information into a speed variable. The second function obtains the controller’s direction to determine the vector variable the user needs to be pushed towards. The final function combines the variables from the previous two and supplements them into an in-built function, ‘add player movement’ which propels the player in their chosen direction.

### 4.3.7 Modular Variables

The implementation of character speed factors as flexible variables was originally intended to be placed in the main level selection screen. Users would only be able to set their variables in the beginning and would then have to stick with the same values until they complete the level. However, during the end of sprint testing sessions, it became apparent that this was not a feasible option; especially for a user that is using a level to get accustomed to a particular paradigm. Moving the variables to a wrist menu instead allows the player to easily change their speed at any point within the level.

A black screen with white text

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Figure 6: Wrist Menu User Interface

Once a change in the speed slider is detected, the new value is immediately updated within the corresponding character movement component of the paradigm by obtaining the current player character and casting it to the relevant character class.

Graphical user interface

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Figure 7: Wrist Menu Blueprint (Speed Slider)

### 4.3.8 Asset Creation and VLE Aesthetics

#### Level Realism and Cohesive Aesthetics

The initial approach to level design was to investigate the feasibility of photogrammetry as a method of deriving photorealistic assets for the scene as a means of building upon place illusion (Slater 2009; Slater et al. 2022). However, it became evident that this was not a viable approach because it would be a time-consuming process that had the potential of being unsuitable for delivery via a VLE due to optimisation decisions discussed in the next section.

Moreover, while photorealism is an effective immersion factor for a VLE’s place illusion (Zibrek, McDonnell 2019), Slater (Slater 2018) notes that it is not the only way to achieve a higher level of immersion. Immersion can also be attained through a more responsive world, one that supports being able to “perceive using the whole body” (Slater 2018, p.432) such as the act of crouching, looking around an object or even reaching out – all of which have been captured through the user’s character developed in conjunction with the navigation paradigms in the previous sections.

Therefore, it was decided that custom 3D assets would be created using 3DS Max and Photoshop to resemble ‘local’ neighbourhoods but would be simplified in terms of detail to avoid unnecessary over-complication. An analysis of the simplified structure of houses in Clifton, Nottingham was done to gain a more comprehensive understanding of how best to approach the structure of the 3D model.

Figure 8: (Left) Image of a house in Clifton, Nottingham (Right) 3D Assets made for the project

The roads, pavements, and road markings also utilise a similar analytical approach to their design. The textures were sourced from Quixel’s Megascans library (Epic Games 2023) and modified in UE 4.27’s materials editor.

#### Optimisation of Visual Elements

Another aspect of the level design phase was the decision to prioritise VLE optimization for deployment. Despite recent technological advances, most consumer-grade HMDs use operating systems with capabilities comparable to those of our mobile devices. Therefore, to ensure seamless operation, apps should steer clear of graphically demanding material.

The initial intention for the integration of road markings was to utilise the engine’s decal feature. During a test deployment of the package, it was noted that the decals hadn’t been generated and in the investigation into the cause, it was found that decals in VR rely on the mobile HDR feature. However, as part of the optimisation decision, mobile HDR must remain turned off during packaging as it severely impacts the graphical quality of the VLE.

As a substitute for decals, the project uses planes and other objects with modified material blueprints to simulate a similar effect.

## 4.4 Prototype Phase 1 – NICER Group Feedback

An application demonstration was conducted with the Nottingham International Consortium for Educational Research (NICER) (Oak Field School 2022) group during their monthly meetings to ascertain whether the initial base requirements had been effectively captured at the end of this prototyping phase. Demonstrating the software to potential users was crucial for receiving feedback that could help identify any issues or areas for improvement.

The session started with a brief introduction of the project along with its aims and objectives followed by a quick demonstration of the different navigation paradigms. The HMD perspective was cast onto a much larger screen for all members of the NICER group to see. Upon completion of the demonstration, the group members were encouraged to provide some feedback on the prototype while 2 of them took turns trialling a paradigm of their choice. The transcript of this session is documented in Appendix **XY**.

### 4.4.1 Trial Observations and Feedback

Both members that requested to trial the application were adults with learning disabilities. The first user chose to trial the thumb-stick method while the second user elected to trial the arm-swinging method instead. Through observation of how both users interacted with the overall application and paradigms, three key areas of improvement were identified.

The first is the need for more easily identifiable ways to depict the appropriate motion controller buttons to press. While describing what buttons the users needed to interact with to trigger movement, it became clear that the terms like ‘trigger buttons’ and ‘grip buttons’ had the potential to be confusing, unclear, or vague for individuals with learning disabilities or even individuals without prior experience with these particular controllers.

The proposed solution would utilise custom materials and a controller mesh for the controllers wherein depending on the paradigm, the button needed to trigger movement would be coloured differently from the rest of the controllers. This would enable users to identify the relevant controller buttons by colour rather than by their more technical name. The controller mesh and colour-coded buttons also provide an additional visual aid for the user as they’ll be able to glance down at their hands while immersed in the VLE and see the same controllers that they’re holding on to while outside of VR. This prevents the need for them to take off the HMD to visually confirm which button to press.

Another area of improvement was derived from a question by one of the NICER group members regarding the ambiguousness of the term ‘target’ when describing a glowing endpoint of a level in a project that was demonstrated prior. While not directly related to this project and its overall user’s experience of the navigation paradigms, it is still a factor that contributes to the overarching VLE experience of this. The project utilises similar visuals for its level endpoint that were noted to be not “concrete” enough in the other project. Moreover, it was highlighted that describing it as a target to users might leave room for “confounding factors” depending on what a user’s definition of a target is. To further build upon this point, members of the NICER group were asked for their definition of a target and most described a target as one that’s used for archery. Similarly, during this project’s demonstration, it was noted that the “picking tool” for the teleportation and walk to point methods seemed more like a “fishing rod” and thus, not “very clear” on where the user is moving towards as a result.

As a result of the above feedback, to achieve a more distinct level endpoint with a stronger visual cue, it was decided that a 3D animated human avatar would meet the criteria. As for the selection tool for the two paradigms, a modification to the generated mesh would include an additional mesh at the tip to indicate the exact point that has been selected.

Finally, concerning the third area of improvement, while the pop-up wrist menu functionality works exceptionally well in a demonstration scenario, in the context of the project, it raised a question regarding the role of the trainer in the VLE delivery.

As a travel training tool for individuals with learning disabilities, control of the settings functionality would ideally be given to the facilitator. Though, in a single-player setup, this isn’t a feasible option as it would require the swapping back and forth of the HMD between the facilitator and the user. Thus, this inspired the need for a multi-user setup; wherein the facilitator would be able to observe and set the variables for the individual experiencing the level via the HMD. However, as a fully functional multiplayer application is out of the scope of this project, an initial prototype will be developed instead before the second opportunity for feedback as a means of determining its efficacy and of whether it should be explored further in future work.

The feedback and observation data from this session were utilised to formulate the implementation plan for the subsequent prototype. The modifications mentioned above were prioritised over any minor additional features to ensure that they were ready to be showcased as part of the second feedback opportunity’s demonstration. The detailed implementation of these three areas is explored and documented in the subsequent section.

## 4.5 Prototype Phase 2 – Implementation of Improvements

### 4.5.1 Material and Mesh Improvements

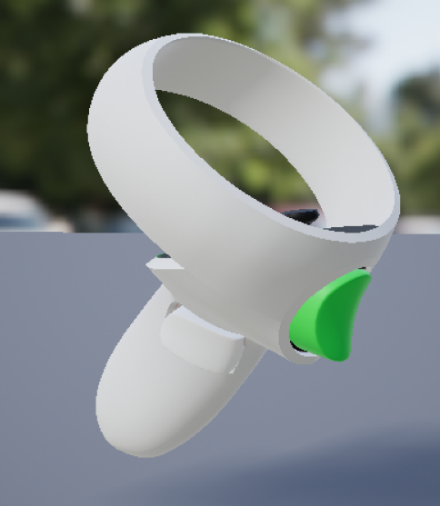
The modifications to the motion controller’s meshes’ was done using the publicly available controller materials (Meta 2022). The material images were edited, and several different versions were created to include different button combinations. Through the engine itself, material blueprints were setup using these images and each material was assigned to its corresponding paradigm’s controller mesh.

Figure 9: Controller meshes using their own custom material

For the teleportation and walk to point paradigm’s selection mesh, a modification was made to the blueprint logic that creates the mesh to include an additional mesh at the end of the loop that would act as an indicator for the current point the user is targeting using the controller.

Graphical user interface

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### A person standing on a green circle Description automatically generated with low confidence4.5.2 Identifiable Targets

To achieve a less vague and more distinct end-level target point for users, an animated waving character mesh was imported from Mixamo (Adobe Systems Inc. 2023). The mesh was then integrated into the existing target point blueprint.

This provides a travel trainer with an identifiable target point that is much easier to describe to a user with learning disabilities when compared to the original vague, glowing green endpoint.

Figure 10: The modified end-level target point

### 4.5.2 Multiplayer Functionality

To achieve multiplayer functionality, the project employs the use of both the PC and HMD perspectives to create its dual-user experience. By running the VLE via the engine itself instead of deploying it, the trainer can control a character of their own via the PC and interact with the individual that’s experiencing the VLE via their character using the HMD.

The PC user was setup to act as the host server. They first need to select the desired navigation paradigm for the VR user to experience and then a server instance is created. The VR user on the other hand acts as a client and can only connect to the host’s server once the PC user has chosen a paradigm.

**A picture containing ground, way

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Figure 11: VR User Perspective (Left) and PC User Perspective (Right)

While in the server, for both users to be able to observe each other’s movement within the level in real-time, modifications to the blueprints to account for replication were made. The VR user’s button inputs are run through the PC user’s device (server) instead of via their own device (client).

**A screenshot of a video game

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Figure 12: Thumb-stick paradigm's modified inputs for replication

## 4.6 Prototype Phase 2 – Travel Training Expert Feedback

To obtain additional feedback on the prototype, a focus group comprising of 5 different travel training experts across the United Kingdom was formed. This phase included 4 demonstrations (2 online sessions and 2 in-person sessions). The purpose of these session was to collect high-quality data from experts that would help drive the direction of the second prototype’s development phase. The chosen structure of the interview was semi-structured. This was done to allow for a mixture of both closed and open-ended questions in case there was the potential to pursue additional information.

In line with research (Reja et al. 2003; Husain et al. 2012; Alsaawi 2014) conducted into designing effective open and closed-ended questions, the questions are designed to be short in nature to avoid risking a decrease in the interviewee’s understanding of the whole question. Similarly, the interview also avoided the use of multi-barrelled questions. Another aim during the design of the questions was to avoid invoking any sense of ambiguity or bias. This was done by first obtaining a definitive answer through a closed-ended question. A subsequent open-ended question was then used to encourage further elaboration. The questions used for these feedback sessions can be found in Appendix **[]**.

The feedback sessions were all recorded and transcribed (see Appendix **[]**) with permission from the participants as it aids in the reduction of claims of researcher bias and allows for a deeper analysis of the participant’s responses (Heritage 1984 and Bryman 2008 in Alsaawi 2014).

* Added modular teleportation distance.
* Identified clear areas of future work for the software (i.e., multi-user system, more maps, controllable situational variables)

Gloucestershire County – 23rd Feb (Online)

Nottingham City – 23rd Feb (IRL)

Lincolnshire – 24th Feb (IRL)

Doncaster – 1st March (Online)

## 4.7 Prototype Phase 3 – Implementation of Additional Features

### 4.7.1 Collision Detection

Collision in VR poses a significant challenge for development as the user’s real-world movements are not bound by the limits of the virtual world. Hence, a restructuring of each paradigm’s component hierarchy **(see Diagram XYZ)** was necessary to include an additional scene component that would act as the user’s origin in relation to the virtual world.

Graphical user interface, text

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Figure 13: Component Hierarchy of the Navigation Paradigms

The collision capsule mechanics itself are broken down into two distinct functions. Both functions are passed through the event tick event so that the checks associated with them are run every tick. This ensures the player’s collision capsule reflects the player’s position and height in the world at any given moment.

The first function recalculates the height of the collision capsule using the current position of the camera. Doing so allows the user to crouch, jump or walk up and down hills and have this reflected in their collision capsule.

Graphical user interface, application

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Figure 14: Update Collision Height Blueprint Function

The second function then realigns the capsule to the position of the camera to prevent it from being detached when the capsule collides with an external factor. Graphical user interface

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Figure 15: Align Collision to HMD Blueprint Function

### 4.7.2 Modular Selection Distance

To achieve a modular teleportation distance, the only change that needed to happen was to introduce a new selection distance slider to the wrist menu. The variable itself had already been implemented during the first prototyping phase, however, it only used a set default value.

Similar to how the speed slider functions, the selection distance slider immediately updates the variable when a change is detected via the slider by casting to the character class.

**Graphical user interface

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Figure 16: Wrist Menu Blueprint (Selection Distance Slider)

# Chapter 5 - Results and Discussion

## 5.1 Preliminary Testing

With the completion of the third iteration of the prototype, preliminary testing could begin. A testing protocol (Gay 2018) was created (see Appendix **[]**) to gather data and additional feedback on user experience concerning the different locomotion paradigms.

Through an information sheet shared with the university’s student population, a total of 8 young adults without learning disabilities with ages between 19 – 25 were sourced using the convenience sampling methodology. While this methodology may not be representative of the application’s target users, it is the least expensive and least time-consuming method of gathering participants for preliminary testing (Taherdoost 2016). Moreover, the primary intention of this testing session is to confirm the effectiveness of the testing protocol in addition to gathering baseline user experience data. To ensure the entire process was conducted ethically and in line with the university’s code of conduct, each participant was provided with a participant information sheet and a consent form.

On the day, participants first received a quick standardised briefing on the session as outlined in the protocol. It was made clear during the briefing that at any point during the session if the participants were to experience any symptoms of cybersickness (i.e., nausea, motion sickness, vertigo, etc.) they would have the opportunity to stop the session to take a break before deciding on whether they would like to end the session at that point or continue. After the briefing, participants were then asked to rate their level of prior experience with Virtual Reality using a Likert scale outlined in the protocol.

Following the completion of the induction process, they received some assistance in putting on the HMD. The participants were then instructed on which paradigm to select from the menu for their level. Throughout the session, while participants completed each level, their interaction with the VLE was observed via the author’s laptop as the VR perspective was cast to that device. Notes were made on any significant observations and on how easily participants figured out how to use a particular paradigm. Additional comments made by participants were also documented. At the end of each task, the participants were asked to rate the paradigm based on three Likert scales outlined in the testing protocol.

After experiencing all five navigation paradigms, participants were asked a few more questions and then given the opportunity to ask questions about the project or provide feedback on the software.

## 5.2 Results and Discussion

Based on the induction question regarding prior VR experience, it was found that 75% of participants had little to no experience with Virtual Reality while 25% reported having moderate to high levels of experience with Virtual Reality. This meant that a majority of participants were not well-versed in the control mechanisms of the Meta Quest 2. Thus, the novel experience for these participants acted as an additional indicator of the difficulty levels of each navigation paradigm. Moreover, it would highlight whether the controller material changes made in the second prototype phase were effective.

During the scenarios stage of the protocol, it was observed that participants navigated the main menu with ease, especially when they needed to select a navigation paradigm. There was only one instance where a participant struggled to select an option, however, they were extremely responsive to guidance when told they needed to use the buttons that were highlighted in green. There were no instances of participants lifting the HMD to observe the physical controller to decipher the controls. Participants with a significantly lower prior experience with VR appeared to have benefitted more from the absence of specific terminology when referring to the control mechanism (i.e., press the trigger or grip buttons) in favour of the more specific and comprehensible instructions of pressing the green button. Moreover, all participants immediately identified the level’s endpoint when told to navigate to the waving man on the opposite side of the road.

Out of all the participants, 7 out of 8 made use of the modular variables available via the left-handed wrist menu. Participant B had a left shoulder injury and needed to wear a sling throughout the session and thus, was unable to access the wrist menu due to it only being available via the left motion controller. From the 7 participants that did use the different options, many made comments that echoed a similar sentiment that the modular speed helped them customise the experience to mimic their actual walking speeds.

While most participants experienced some level of difficulty while using the jogging on the spot paradigm, participants B, C, E, G, and F expressed a distinct dislike for the paradigm as they noted it was either “too uncomfortable to use” or needed “very specific movement” to work “that isn’t very obvious”. When asked to elaborate, the remark on the paradigm’s discomfort was found to be due to how much physical effort and movement it required of the participant. Meanwhile, participant C, noted their discomfort stemmed from a brief moment of nausea they experienced while using the paradigm.

In an analysis of user ratings of each paradigm based on how comfortable their user experience was after each paradigm was trialled **(see diagram XYZ)**, teleportation received the highest average rating for this category while arm swinging was a close second. This echoes the conclusions drawn in existing research discussed in the context section wherein teleportation is believed to be the best navigation paradigm for virtual reality on the basis of user comfort.

Arm swinging received only a slightly lower average rating than teleporting due to 2 users stating that it required too much physical effort to trigger. However, despite this critique of the paradigm, it appears to have still been perceived to be more comfortable than low effort navigation paradigms like thumb-stick and walk-to-point. In line with comments made during testing, Jogging received the lowest average rating for this category.

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Figure 17: Average Comfortable User Experience Rating of the Navigation Paradigms

Regarding ease of use, the Thumb-stick paradigm received the highest average rating while jogging received the lowest average rating of the category. **[CONTINUE]**

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Figure 18: Average Ease of Use Rating of the Navigation Paradigms

For the final Likert scale focusing on the degree of realistic movement, the Arm Swinging paradigm received the highest average rating while the walk-to-point paradigm was a surprisingly close second instead of Jogging. It can be inferred from participant comments and the performance of Jogging on the two other scales that the paradigm being difficult to use and having an overall uncomfortable user experience might have potentially influenced its performance in this category. Teleportation received the lowest average rating within this category as anticipated as it does not attempt to simulate the experience of walking for the user.

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Figure 19: Average Realistic Movement Rating of the Navigation Paradigms

At the end of the testing session, when asked which navigation paradigm they were most likely to use, 4 participants picked arm swinging, 3 picked teleportation and 1 picked thumb-stick. Participant E did go on to elaborate that if their answer was entirely focused on the realism aspect, they would instead choose arm swinging over teleportation. Participants that chose arm swinging explained that this was because the paradigm was the “most natural to do” and that it felt “close to actually walking”.

When asked which paradigm they’d be the least likely to use, 6 participants picked jogging, 1 picked teleport and 1 picked walk-to-point. Based on findings related to the jogging paradigm explored in the earlier parts of this section, this result is as expected. Participants expressed having a significantly unsatisfactory experience with the paradigm due to its difficult user experience. Participant D picked walk-to-point and noted that it was because the paradigm moving them without them directly contributing to the movement outside of the target location selection made them a “tiny bit nauseous”. This confirms a similar observation received during the second prototyping phase’s feedback session wherein experts noted that the thumb-stick and walk-to-point paradigms felt more like “gliding” rather than walking. Participant F noted that their choice of Teleport was in part due to all the other paradigms feeling more realistic in their imitation of walking where one could “feel the motion”. Teleportation, on the other hand, felt like “skipping” for them and thus, not as favourable of an option compared to the other paradigms.

Participants were also asked whether the modular variables wrist menu had any influence on their overall user experience, and all participants said yes. Participant D went on to elaborate that the default movement “felt too slow” and the modular speed meant they could pick a speed that felt more like what “they’re used to”. Participant G expressed their contentment with having the option to option to increase the selection distance for the teleportation and walk-to-point paradigms.

Finally, when prompted for additional feedback, Participant A shared that the arm swinging paradigm experience was visually smooth and that it was quite a responsive paradigm. Participant F remarked that each paradigm had its own clear set of instructions that was “easy to follow” and very “nicely executed”. Participant E suggested that the left-handed wrist menu allow item interaction and selection using the left thumb-stick instead of requiring that the user interacts with the menu using the right-handed trigger button.

Using the data collected during this testing session, to determine the most suitable paradigm based on the three Likert scale categories, the average results for each paradigm were multiplied against each other using the following formula:

*Average Comfort Score x Average Difficulty Score x Average Realism Score*

The paradigm with the highest score based on the formula above is the arm swinging paradigm with a score of 74.25 while the paradigm with the lowest score is jogging with a score of 28.08.

Arm swinging as a locomotion paradigm for virtual reality excels in all outlined categories of success. It is an easy-to-use paradigm that is both a comfortable experience for the user and one that has been highly rated as a paradigm that feels closest to realistic walking movement.

On the other hand, teleportation was ranked only slightly above jogging based on its overall score. This further solidifies the notion presented in the new ideas section that while teleportation is an effective navigation paradigm for VR spaces due to its ability to successfully allow the user to navigate a virtual space with minimal influence of motion sickness, the absence of realism in how it presents movement to the user is what ultimately makes walk to point the more favourable locomotion paradigm in the context of travel training. Despite there only being a slight modification between the two, walk to point’s showcase of the actual journey a user makes from one point to another further builds upon their perception of movement. Thus, making it the more realistic movement from the user’s perspective.

# Chapter 6 – Conclusion and Future Work

## 6.1 Conclusions

In conclusion, this project facilitated the research and implementation of five different navigation paradigms, each with their unique approach to simulating locomotion as a means of determining the most effective method of navigation from the perspective of individuals with learning disabilities. Each paradigm was assessed on the basis of three key criteria derived from travel training expert feedback and an analysis of how discomfort influences the user experience.

While testing results point to arm swinging being the most favoured paradigm on the basis of the aforementioned criteria, each of the five paradigms come with their own merits and pitfalls. Through expert feedback, it is clear that the success of the project lies not only in its determination of the most favoured method, but also in the collective existence of the paradigms providing users with the ability to choose one that best fits their needs. The user experience is a “subjective impression” (Santoso, Schrepp 2019, p.2) and thus, the offer of flexibility to decide how one wishes to experience a travel training level ensures that the user is in control of their own sense of comfort. As a result, the five paradigms have been encapsulated within an Unreal Engine 4.27 plugin and will be hosted via GitHub (GitHub Inc. 2023) as an open-source resource for VR developers and researchers to utilise.

Yet, this project has limitations. Though the preliminary testing results provided a foundational understanding of how users perceive these different navigation paradigms, its sample size was unrepresentative of the application’s target audience, individuals with learning disabilities. Hence, the findings cannot be generalised as there is the potential that individuals with learning disabilities might perceive these navigation paradigms differently. Moreover, the project would have benefitted more from a long-term investigation into the efficacy of the paradigms as it would provide more insight into whether user opinions evolve over time and whether their overall experience is impacted by long term exposure.

Overall, this project was successful with a few limitations that can be addressed through the avenues discussed in future work. Its success is backed by the supportive reaction of the travel training experts during the demonstrations wherein the project was described to have had “a massive progression in detail” since the previous iteration and that “it would really benefit the work” the travel trainers are currently doing in schools.

## 6.2 Future work

While there are numerous potential avenues for future work in relation to this project, outlined below are 3 identified areas that would benefit from additional research based on travel training expert feedback.

### 6.2.1 Long-term Paradigm Testing

As discussed in an earlier section on the project’s user-centred design approach, this is a pilot study. As a result, there is a need for a long-term investigation into the effectiveness of the different navigation paradigms developed in this study on the basis of user comfort and experience. Moreover, it would be beneficial to quantify these findings using validated measurement tools such as the Simulator Sickness Questionnaire (SSQ) (Kennedy et al. 1993) or VR Sickness Questionnaire (VRSQ) (Kim et al. 2018). A long-term investigation into user preference would present a better understanding into whether there is a distinctly more favourable navigation paradigm when compared to others.

During interviews with the experts, all expressed some degree of interest in supporting this ongoing research and as a result the full transcripts and contact information is available via the appendices. As a result, there is the possibility to invite and formulate a focus group of travel training experts that would help facilitate the future work and research into developing an improved version of the VR travel training tool.

### 6.2.2 Exploration of Multiplayer Delivery

As multiplayer delivery of the overall travel training tool was only briefly explored in this project, there is the potential for future work in this area. As noted by all 5 travel training experts during the feedback sessions, all of them noted that the flexibility to switch between single and multiplayer would be ideal. A common point was that each delivery style had its own benefits wherein the multiplayer setting had the potential as an early-stage teaching tool and the single player setting may be better suited for more experienced and independent travel confident individuals.

Debbie from Doncaster County Council also suggested that there is the possibility to utilise the multiplayer setting outside of the context of just a travel trainer and their student. Instead, she noted that it could be beneficial to have multiple students within the same VR level so that she as a trainer could assess how her students would behave in that setting when in the company of their friends and not on their own.

Subsequently, multiplayer delivery has the added benefit of enabling parents or guardians to participate in the training as well. Thus, this is another area of future work that has the potential to significantly benefit its user base as its supported by actual user data collected in this project.

### 6.2.3 Development of the VLE Setting

The research into navigation paradigms is a subset of a much larger project, developing a fully immersive and comprehensive VR travel training tool. With this comes the need to develop a proper environment with vehicles and pedestrians that respond to the player’s actions. Moreover, a particular focus on the development of different, customisable levels that include all sorts of road crossings would also supplement the overall VLE experience. As noted in the feedback in all four interviews with travel training experts, they are actively seeking out a tool to support the work they currently do. Some want a VLE for initial demonstration purposes, while others prefer a VLE designed to act as “homework” for their students. Hence, from a future work perspective, it would be beneficial to utilise the interview feedback (see Appendix **A, B, C, and D**) while formulating a development strategy for the VR travel training tool.

In either case, there should be some reference to future work, either to forward and expand on the successful outcome or to test ways of overcoming the shortfall in your ideas that didn't work out quite as expected but there should be something that shows you can see further implications of what you have achieved.

## 6.3 Legal, Social, Ethical and Professional Issues

### 6.3.1 Legal

This project will include the use of participant test result data alongside interview feedback data during its implementation phase. Thus, in compliance with the existing General Data Protection Regulation (GDPR) (Proton AG 2022) and the Data Protection Act 2018 (The National Archives 2018) surrounding data collection and use, all participants involved in the project will be made aware of how their data will be processed in a “concise” and “transparent” manner (GDPR, Article 12). Additionally, participants will be allowed to request the deletion of any information we have on them at any point during or after the project (GDPR, Article 17). Furthermore, the collected information will not be used for “personal gain” or to “benefit a third party” as confidential information will not be shared without the “permission of a relevant authority or as required by legislation” (British Computing Society 2022, Section 3.4).

### 6.3.2 Social

A crucial element of the BCS Code of Conduct is the use of technology with “public interest” in mind. From the perspective of this project, the development of a new and improved version of independent travel training technology can help counter obstacles that individuals with learning disabilities tend to face when it comes to gaining independence through travel. The findings of this project will be methodically documented so that it may supplement existing research into this topic area as this project constitutes a small part of a wide array of VR adaptations to ensure those with disabilities have equal access to educational tools that can benefit them. Furthermore, the final prototype developed will be shared with members of the NICER (Oak Field School 2022) group so that they have access to a more up-to-date version of the application.

### 6.3.3 Ethical

This project aims to “treat all persons fairly and with respect” and intends to “not engage in harassment or discrimination, and to avoid injuring others” in line with the IEEE (Institute of Electrical and Electronics Engineers 2020) Code of Ethics as a key aspect of this project will involve user acceptance testing via a session with its actual user group. As the project’s target group are individuals with learning disabilities there is an additional level of care that must go into the overall process to ensure that there is “due regard for public health, privacy, security and wellbeing of others” (British Computing Society 2022, Section 1.1). To guarantee this, a thorough document highlighting the methods and procedures of this project will be submitted as part of the Non-Invasive Ethics application to obtain a sign-off from the relevant academic body.

### 6.3.4 Professional

To ensure the maintenance of the professional integrity of this project with the aim of “upholding the reputation and good standing of BCS” (British Computing Society 2022, Section 4.3), several different guidelines shall be considered. The BCS highlights that one’s “duty to the profession” involves acting with “respect” and integrity” in addition to seeking to “improve professional standards”. To achieve this, the project will adhere to the university’s Student Code of Conduct (Nottingham Trent University 2022). This includes ensuring that throughout the lifecycle of the project, there will be no engagement in plagiarism, collusion or other actions that would result in a violation of the NTU Academic Irregularities Code of Practice. Subsequently, as this project will rely on the facilities provided by the university, the adoption of good practices based on the NTU Computer Use Regulations will be incorporated as well.

## 6.4 Synoptic Reflections

This project is a testament of my growth as an upcoming developer within the industry. The most poignant factor being my newfound proficiency in using Virtual Reality (VR) and Games development tools such Unreal Engine and 3DS Max. While reflecting back on my initial exposure to VR, I recall struggling with my attempt to make modifications to the engine’s VR template. The memory acts as a stark contrast to my capabilities now where towards the end of the prototype’s phase 3, I had become far more comfortable with taking apart that exact same template to modify different parts of it.

Aside from the technical benefits of this project, my confidence in both the subject material and as a presenter have flourished as well. Actively having to seek our expert opinions on my prototypes, while an intimidating experience, was nevertheless an extremely beneficial opportunity to have as it mirrors what would typically happen in industry. Moreover, having to analyse feedback and formulate an implementation strategy has taught me how to better manage my project’s scope and time.

The intention behind this project was to develop something that would serve a purpose beyond being what inspired my dissertation. It needed to be beneficial to a wider audience, and I do believe that I have achieved that. While the information gathered on locomotion paradigms in this project is capable of supplementing future work in the area, the locomotion paradigms themselves now being made available to the general public as an open-source plugin ensures that more people are capable of benefitting from the work behind this project.

From the perspective of my career aspirations,

The plugin can be applied in all sorts of scenarios by UE developers from simple VR games to more complex serious games applications. The plugin prevents the need for developers to have to

This section will comprise a reflection on the project concerning employment aspirations and the skills that you have developed towards this through engagement with the project.

# Appendices

## Appendix XX – Requirements List

## Appendix XX – Requirements Analysis

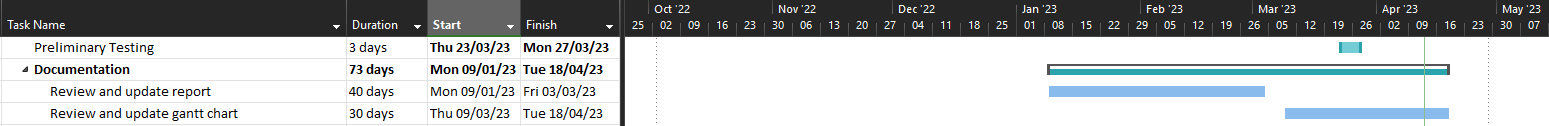
## Appendix XX – Gantt Chart

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## Appendix XX – Risk and Mitigation

Each project risk is assessed based on its probability and impact using a scale of 1 to 5 wherein a value of 1 implies that this risk has either a high probability of occurrence or that if this risk were to happen it will have little to no impact on the project’s progress. A value of 5 implies either a very high probability of occurrence or if this risk were to happen it will seriously impact the project’s progress.

The risk score is calculated by multiplying the probability by the impact score to determine its overall potential influence on the project’s progress with a higher score indicating greater severity. In certain cases, with high-impact risks, the mitigative cost might be far greater than others and thus the risk will still need to be taken for the project to continue.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **No.** | **Risk Description** | **Probability**  **(1 – 5)** | **Impact**  **(1 - 5)** | **Risk Score**  **(P x I)** | **Mitigative Action** |
| 1. | Insufficient knowledge and background research on virtual reality or travel training methodologies. | 1 | 4 | 4 | All the necessary background research will be conducted before the implementation of the solution through a wide variety of sources as highlighted in the Resource section of this document. |
| 2. | The project suffers from scope creep due to objectives not being well-defined and thus the project becomes too complex. | 2 | 5 | 10 | Clear objectives will be established during the early stages of the project and with the use of Agile methodology, any required changes will be thoroughly and frequently reviewed before approval. |
| 3. | The chosen resources are not suitable for the project. | 2 | 3 | 6 | A thorough review of the required resources will be conducted, and a justification will be provided based on research done before the start of the project. |
| 4. | The project suffers from a time crunch due to poor scheduling. | 2 | 5 | 10 | A Gantt chart will be used to map out key deliverable dates and will include the necessary flexibility in case a certain element requires more time than previously anticipated. |
| 5. | Loss of some or all of the project’s 3D assets. | 2 | 4 | 8 | All assets will be backed-up via a hard drive in addition to being stored on a private GitHub repository. |
| 6. | Loss of some or all the project’s documentation. | 2 | 4 | 8 | All documentation will be backed-up via a hard drive in addition to being stored on a private GitHub repository. |
| 7. | Loss of some or all parts of the Unreal Engine project files. | 2 | 4 | 8 | All Unreal Engine project files will be backed-up via a hard drive in addition to being stored on a private GitHub repository. |
| 8. | Equipment malfunctions during the testing stage | 3 | 4 | 12 | All equipment will be tested a day before the actual testing session in addition to being tested once again before the session begins to ensure everything is still functional. A backup set of equipment will be prepared when possible. |
| 9. | A major bug is found during the testing stage. | 2 | 4 | 8 | The project will follow the agile approach of frequent testing at the end of sprints to prevent major bugs from slipping through till the end of the project timeline. |
| 10. | Due to the shared use of Virtual Reality headsets and gear, participants might be at risk of COVID-19. | 3 | 3 | 9 | All equipment will be sanitised before and after each testing session in addition to being sanitised between use by testing participants. All participants will also be asked if they’ve had any symptoms before joining the testing session. |
| 11. | Participants experience some form of headache or eye strain because of the extended use of the VR application. | 3 | 2 | 6 | Participants’ time spent immersed in the application will also be limited as a means of reducing the probability of the risk’s occurrence. |
| 12. | Participants experience some form of motion sickness, nausea, or vertigo because of the VR application. | 3 | 2 | 6 | A discussion will be had with the participant before, during and after the testing stage to identify and mitigate any risks. Their well-being will be monitored to spot any adverse reactions to the application during the session. Participants’ time spent immersed in the application will also be limited as a means of reducing the probability of the risk’s occurrence. In the case they do experience any of the risk’s symptoms, they will be invited to have a break and allowed to continue later once they have recovered. |

## Appendix XX – Prototype Demonstration (NICER Group)

## Appendix XX – Focus Group Interview Questions

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## Appendix XX – Participant Interview Information Sheet (Online)

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## Appendix XX – Participant Interview Information Sheet (In-Person)

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## Appendix XX – Participant Interview Consent Form (Online)

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## Appendix XX – Participant Interview Consent Form (In-Person)

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## Appendix XX – Interview with Gloucestershire County Council (Tim Griffiths)

## Appendix XX – Interview with Nottingham City Council Demo (Roshni Devani)

## Appendix XX – Interview with Lincolnshire County Council (Sandy Carruthers and Mike Powell)

## Appendix XX – Interview with Doncaster County Council (Debbie Easter)

## Appendix XX – Participant Recruitment Information Sheet

## Appendix XX – Participant Testing Consent Form

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## Appendix XX – Testing Protocol

This protocol is divided into 3 distinct parts: the introduction, the scenarios, and the conclusion.

### Introduction

Read the following brief out to the participants at the start of the session as a means of introducing them to the project while highlighting the purpose of the session.

*This Virtual Reality Travel Training tool has been an ongoing project for a few years. With each iteration, the software is modified to better suit the needs of its users. In the previous iteration, we noticed that there was a need to further investigate the role locomotion paradigms and movement play in a user’s overall experience of the virtual learning environment.*

*Ideally, we’d have a boundless space to work with for VR movement, however, this is not always feasible. As a result, there is a need for more stationary solutions to be developed. The focus of the session today is to determine which of the 5 methods you experience today is best suited for the travel training context of the project in terms of its usability and comfortability from a user’s perspective.*

*Before we begin, I would like to reiterate that if at any point you experience any form of discomfort, feel free to remove the headset and take a break. You may then choose to end the session at that point or continue after the short break. The testing session while immersed in VR will last no longer than 15 minutes. Once in VR, you’ll be instructed on which paradigm to select. Each paradigm has a short description available via the menu for you to read before you begin the level. Once in a level, the buttons highlighted in green indicate what you’ll need to press to trigger an action. If you press the left controller’s menu button, the one with the three horizontal lines, you open up additional choices. These choices let you customise your locomotion experience by changing variables such as speed or selection distance. You’re free to use these choices whenever you’d like while in a level. The goal of each level is to get to the person waving at you on the other side of the road. At the end of each level, you’ll be asked to rate it based on two different scales.*

### Scenarios

Each locomotion paradigm level is a scenario for the user to test. To avoid the influence of anchoring bias or any other potential cognitive bias on the user concerning the paradigms, each user will be provided with a different order in which they should experience the different scenarios.

Upon completion of a scenario, the participant will be asked the following questions:

* Please rate that paradigm on a scale of 1 (Extremely uncomfortable user experience) to 5 (Extremely comfortable user experience)
* Please rate that paradigm on a scale of 1 (Extremely difficult to use) to 5 (Extremely easy to use)
* Please rate that paradigm on a scale of 1 (Extremely unrealistic movement) to 5 (Extremely realistic movement)

### Conclusion

Once all the scenarios have been tested, the participant is instructed to take off the HMD and is given a final set of questions to answer.

* Of all the options available, which locomotion method would you be most likely to use? Please elaborate on why if possible.
* Of all the options available, which locomotion method would you be least likely to use? Please elaborate on why if possible.
* Did the extra controls via the left controller menu have any influence on your overall user experience? Please elaborate on why if possible.

After participants have answered these questions, they are encouraged to provide any additional feedback on the software and have the opportunity to ask questions about the project itself.

* Do you have any additional feedback or insight that you’d like to discuss concerning the different locomotion methods?

## Appendix XX – Participant Scenario List

Outlined below is the order in which each participant experienced the different paradigms. The order of each was randomly generated using an online randomiser (Random.org 2023).

* Participant A: Teleport, Thumb-stick, Arm Swinging, Jogging, Walk-To-Point
* Participant B: Thumb-stick, Walk-To-Point, Teleport, Arm Swinging, Jogging
* Participant C: Teleport, Arm Swinging, Thumb-stick, Jogging, Walk-To-Point
* Participant D: Arm Swinging, Thumb-stick, Walk-To-Point, Jogging, Teleport
* Participant E: Jogging, Teleport, Walk-To-Point, Thumb-stick, Arm Swinging
* Participant F: Thumb-stick, Jogging, Walk-To-Point, Arm Swinging, Teleport
* Participant G: Teleport, Thumb-stick, Walk-To-Point, Arm Swinging, Jogging
* Participant H: Walk-To-Point, Arm Swinging, Jogging, Thumb-stick, Teleport

## Appendix XX – Video Demonstration Link

## Appendix XX – VRWalkin’ Plugin Installation Guide

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