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# Chapter 1 - Introduction

## 1.1 Introduction

## 1.2 Aims

The primary aim of this project is to explore the viability of Virtual Reality (VR) to assist people with learning disabilities with independent travelling.

A subsequent aim of this project is to demo a suitable system through a VR1 study (Birckhead et al. 2019) that enables individuals with learning disabilities to navigate a virtual space with ease and comfort.

## 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.
* Learn and gain an in-depth understanding of the experiences of those with learning disabilities, especially regarding independent travel.
* Prototype a VR Travel Training application that aligns with existing research and includes new ideas to create a useful tool that can be used by people with learning disabilities to build up their independent travel confidence.
* 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 VR’s role in treating and educating neurotypicals (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 primarily due to VR’s ability to model the real world in a safer and more controlled manner. Moreover, studies (Brooks et al. 2002; Rose et al. 2002) 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) in those scenarios with the addition of a high success rate for the application at 93.8%.

The results from the predecessors to this project echo similar conclusions. To expand upon the existing knowledge of VR’s efficacy in this area, a review of relevant publications has revealed a reoccurring theme.

### 2.2.1 Navigation and Interaction Paradigms

It can be inferred from the literature review 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.

For non-immersive environments, these findings have been well documented (Standen et al. 2006). The results of the study 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).

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 using joystick” (Brown et al. 2002, p.186) on the Zebra crossing level.

Similarly, a few other 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). These studies did not pursue an investigation into navigation methods. However, questionnaire answers revealed contradictory findings wherein 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 in some cases. Most notably, there seem to be conflicting views on whether joysticks are an ideal method for navigation; this may be due to everyone’s unique needs and experiences. Moreover, through participant feedback a user’s personal preference for first and third-person perspectives was noted to be yet another element of navigation that dictates user experience, thus emphasising the need for perspective and controller flexibility when implementing locomotion into the application.

The remaining studies (Strickland et al. 1996; Simões et al. 2018; Bernardes et al. 2015) 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.

Thus, the discussion above leads to the project’s aim of determining the most effective method of navigation from the perspective of people with learning disabilities. To measure its efficacy, one other element of virtual reality needs to be considered, discomfort through motion sickness.

## 2.3 Discomfort and User Experience

To thoroughly capture the requirements needed to develop comfortable and easy-to-use navigation paradigms, one needs to first analyse the factors that contribute to users experiencing discomfort.

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”, “content” and “human factors” (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 **(ref here)**, 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 Oculus 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. This project intends to be a pilot study into quantifying learning disabilities as a motion sickness human factor from a travel training simulator perspective. 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 **(ref here)**, 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 the studies by Fernandes et al. and Kobayashi et al., 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 hand 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 **(ref here)**. 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, player 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 navigational 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 **(ref here)** 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 **(ref here)**. 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 navigation from a counter-intuitive angle. Another method that incorporates both the speed and rotational movement parameters would be to implement a modified version of popular ‘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 (Barbieri et al. 2018; Gabbard et al. 1999).

To thoroughly capture and evaluate user experiences surrounding navigation paradigms in VLEs, 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 with experts will look to gather requirements concerning navigation paradigms and ways in which existing solutions can be modified to provide greater levels of comfort and overall improved user experiences.

This feedback will be used to inform the design and implementation process for the initial prototype. The prototype will include all the key navigational requirements in addition to a few travel training elements (i.e., crossing levels and road hazards) as outlined in the New Ideas section.

The focus group will be an opportunity for the target user group to trial the prototype and provide user experience feedback on the application. The focus group 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 navigation 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 second stage prototype. This prototype will include the necessary changes derived from the feedback and all the minimum viable product (MVP) features as outlined during the requirements gathering stage.

These findings of the pilot study can then be used to supplement future work involving a long-term investigation into a user’s preferred navigation 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 effectively reduces the likelihood of user discomfort caused by these paradigms, the application must utilise the relevant content factors as design decisions. To ensure the scope of the project isn’t exceeded, this pilot study will focus on the optical flow and controllability factors first.

### 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 especially 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, they still do come at a cost. 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 navigation paradigms. These existing solutions can be utilised in future work as comparison factors when attempting to quantify user discomfort levels as a means of determining the most suitable navigation paradigms for the application.

### 3.1.2 Optical Flow

As indicated in an earlier section, speed and rotational movement are parameters that influence how optical flow can negatively impact a user’s comfort level in a virtual environment. In most VR games and simulations, teleportation has become the preferred mode of navigation. Within the application’s context, however, this navigation paradigm defeats its primary learning objective which is to be a travel training simulator wherein it gets the users to mimic real-world behaviours via the VLE. Hence, the need for an alternative solution that accounts for speed and rotational movement parameters.

One such solution can be seen in VRChat which is its use of 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 attempt to implement a similar version that utilises the first-person perspective instead. Moreover, modular speeds across all navigation paradigms are another solution that might improve user experience. 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 gesture tracking or through thumb stick movement.

## 3.2 Primary Interaction Paradigm Features

Based on the design factors discussed above, this application will include the implementation of three main 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 Walk-to-Point Navigation

A potential modification to the teleportation method is using it to facilitate the ‘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 navigation 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 navigation paradigms to be assessed in terms of their ease of use and comfort.

### 3.2.2 Arm-Swinging Gesture Navigation

Another navigation paradigm that will be implemented would employ the use of arm-swinging gestures as a means of capturing locomotion input. In a previous iteration of the project, this paradigm appeared to be the more favourable form of navigation based on user feedback. The paradigm successfully creates an active user experience in addition to staying within the limited space boundary. Moreover, this paradigm provides users with an alternative navigation method, especially for users with learning disabilities 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.

### 3.2.3 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 few different design modifications. The implementation of this paradigm would utilise the axis of thumb-stick movement to dictate the back-and-forth and side-to-side player movement.

### 3.2.4 Jogging in Place Navigation

[ Insert Stuff here ]

## 3.3 Additional Paradigm Modifications

### 3.3.1 Flexible 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 Delivery

The delivery of this paradigm, however, will allow for flexibility. The user can choose to either remain seated and swing their legs back and forth on a chair like the Cybershoes approach or they could stand up and walk in place using an additional rotation controller to dictate the direction of their player’s movement. The other design modification applied is the speed parameter which is discussed in the following section (Section 3.2.4).

### 3.3.3 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 Agile 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.

## 4.2 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 have two testing phases in which the initial one will be used to gather feedback from the clients on any bugs or requirements that they would like the project to address. |
| 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. |

## 4.3 Implementation of Navigation Paradigms

### 4.3.1 Pawn and Character Classes

During the early stages of development, the project utilised Unreal Engine 4.27's (UE 4.27) Virtual Reality template. This template came with a pre-made VR pawn for the user that had stepped-turning and teleportation locomotion implemented. In the beginning, modifications to the VR pawn were minimal and as such, there wasn’t a need to look at alternative class options. However, when the walk-to-point mechanism needed to be implemented, challenges began to arise due to the lack of flexibility that comes from the Pawn blueprint class when compared to the Character blueprint class.

One key challenge is that the pawn class does not come with the character movement component. Hence, to achieve a similar effect while using variables like speed and velocity, 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 remaining locomotion methods (i.e., walk-to-point navigation, jogging in place navigation and arm swinging navigation) and the modification of the already developed ones (i.e., thumb-stick navigation) as in-built functions like set velocity, set speed, and move to location could be called without the need to develop a unique set of functions. This decision ultimately saved the project several days’ worth of development time as well since there wasn't a need to reimplement existing inbuilt functions to work with the pawn blueprint class. Moreover, by developing the character classes without the existing blueprint logic that came with the template’s pawn blueprint, it meant that each character blueprint was designed with a strict purpose in mind and did not include any additional, unnecessary features (i.e., grabbing functionality).

### 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 : 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

Description automatically generated with medium confidence

Figure : 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 Walk-to-Point Navigation

This paradigm is derived from an implementation of a teleportation paradigm that was developed prior as a means of forming the fundamental logic behind walk-to-point navigation. 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 : 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

Description automatically generated

Figure : Navigation area in a level

### 4.3.5 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.

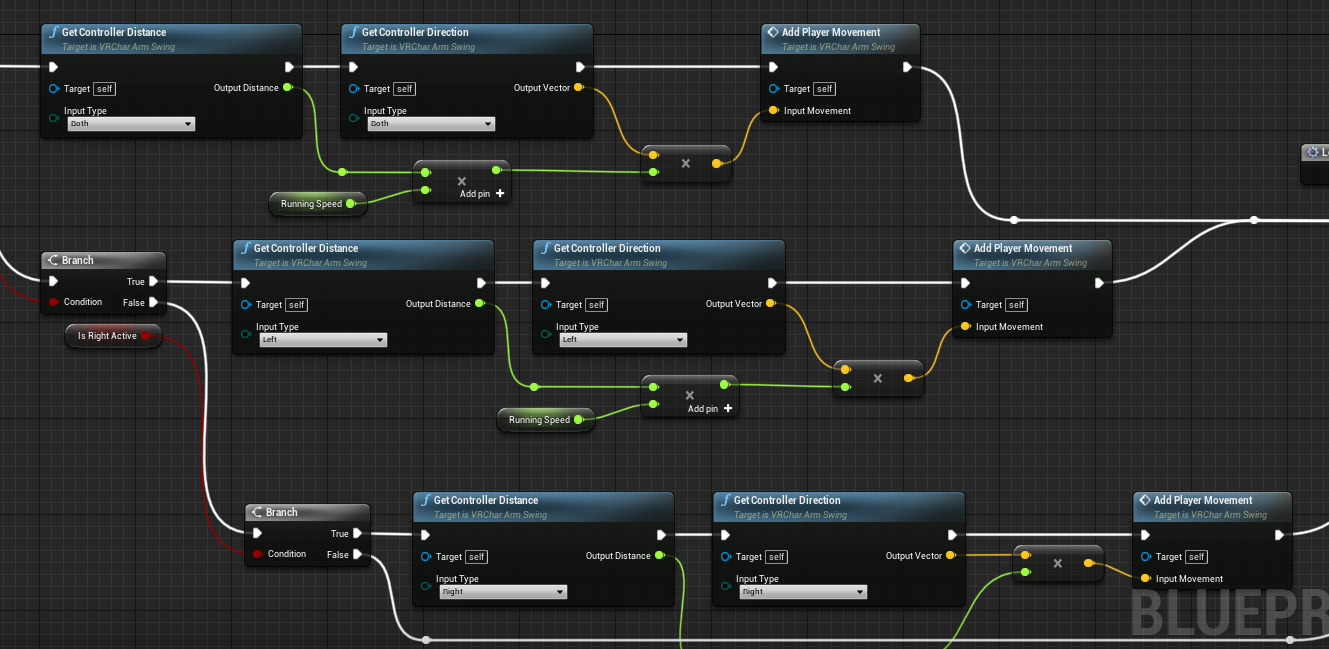


Figure : Arm Swinging Navigation Blueprint

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.

### 4.3.6 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

Description automatically generated with low confidence

Figure : 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

Description automatically generated

Figure : Wrist Menu Blueprint (Speed Slider)

The wrist functionality works exceptionally well in a testing scenario but in the context of the project, it raises one key question regarding the role of the confederate 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 dual-user setup; one where the facilitator would be able to observe and set the variables for the individual experiencing the level via the HMD.

The prototype implementation of this concept involves the use of a combination of PC and HMD perspectives to create a 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.

## 4.4 Implementation of Additional Features

### 4.4.1 Automated Vehicles and Collision Detection

Discussion of collision capsule mechanics

### 4.4.2 Asset Creation and VLE Aesthetics

#### Level Aesthetics and Setting

When designing assets for the different levels, it was clear that it would be best to create an environment that best resembled ‘local’ neighbourhoods and streets. However, most assets that are currently available are designed with an American audience in mind. The initial approach was to investigate the feasibility of photogrammetry as a method of deriving assets for the scene. It quickly 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.

Therefore, the alternative approach was chosen. The 3D assets that needed to be designed to resemble ‘local’ neighbourhoods would be created using 3DS Max and Photoshop 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 : 3D Assets in a level

The roads, pavements, and road markings also utilise a similar analytical approach to their design. The textures were sourced from Quixel’s Megascans library **[ref here]** 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.

## 4.5 Prototype Feedback and Improvements

### 4.5.1 Prototype Phase 1 – NICER Group

* Talk about the identifiable button materials
* Adding an identifiable end-point not a ‘vague’ target as the understanding of a target can differ between users

### 4.5.2 Prototype Phase 2 – Travel Training Experts

To obtain additional feedback on the prototype, a focus group comprising several different travel trainers across the United Kingdom was formed. This phase included 4 demonstrations (2 online sessions and 2 in-person sessions). The purpose of the 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 will also avoid the use of multi-barreled 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 is 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)

## 4.6 Testing

As this project is a pilot study into the overall effectiveness of the implemented locomotion paradigms concerning usability and user comfort while in a travel training VLE, it requires a testing protocol (Digital Education Strategies 2019) to be developed. Thus, a testing protocol was created (see Appendix **[]**) on how to go about efficiently assessing the effectiveness of the different locomotion paradigms. To first trial the protocol in addition to gaining some baseline data, a sample of young adults without learning disabilities will be used.

Through an information sheet shared with the university’s student population, a total of **[]** participants with ages between 18 – 26 from the local area were sourced. From the total number of participants, **XX%** have had little to no experience with Virtual Reality while **XX%** reported having moderate to high levels of experience with Virtual Reality. Before the testing sessions, each participant was provided with a participant information sheet and a consent form to ensure the entire process was conducted ethically.

On the day, participants first received a quick standardised briefing on the session as outlined in the protocol. Then they were given the HMD and controllers and asked to experience each navigation paradigm in the order that they were given. 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. They were then given the opportunity to end the session at that point or continue with the rest of their tasks. Upon completion of the tasks, the users were asked a series of questions as outlined in the protocol. The participants then had the opportunity to ask questions or provide any additional feedback on the software.

# Appendices

## Appendix 1 - Legal, Social, Ethical and Professional Issues

### 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).

### 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.

### 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.

### 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.

## Appendix 2 – Gantt Chart

## Appendix 3 – Focus Group Interview Questions

Text

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## Appendix 4 – Testing Protocol

As this is a testing protocol for a pilot study, the primary intention is to garner additional user feedback on the software’s main locomotion features. In subsequent iterations of this study, testing should be conducted using validated measurement methods such as the Simulator Sickness Questionnaire (SSQ) (Kennedy et al. 1993) or the VR Sickness Questionnaire (VRSQ) (Kim et al. 2018). This protocol is divided into 3 distinct parts: the introduction, the scenarios, and the conclusion.

### Session 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 via the menu. At the end of each paradigm level, you’ll be asked to rate it based on two different scales.*

### The 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) to 5 (Extremely Comfortable)
* Please rate that paradigm on a scale of 1 (Extremely hard to use) to 5 (Extremely easy to use)

## 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.

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 prototypes?

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