Game Design:
Motivating Physical Movement in Aging Adults
Using VR

by
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Abstract

I present the design intentions and process of Lumapath, a virtual reality (VR) game designed to encourage movement in aging adults, with and without arthritis, in a safe and controlled way. I demonstrate how user testing was a crucial part of the design decisions and present the results of a pilot study that was conducted using the game and 28 participants. Overall, my results show that VR has a lot of potential as a tool for motivating aging adults to be physically active. While the specific needs of any group should be taken into consideration, the limitations of aging emerged as extremely important factors because of how these factors can fundamentally affect or frame the way these users experience their virtual surroundings. Future considerations that emerged from the design and testing of this VR project are also discussed. These range from issues of how the user testing can be improved to more wide-ranging considerations of what should be taken into account when designing for this demographic.

Keywords: game design; VR; aging; physical activity; range of motion
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Chapter 1.

Introduction

Games have increasingly become one of the most important forms of media that impacts our society today. State of Online Gaming Report, for example, states that more than 15% of the world’s population play games. Focusing only on the world’s online population, over 44% of that population plays online games (Spil Games, 2013). To put that another way, almost half of all the online population in the world plays some kind of video game. However, games are not only used for entertainment anymore. Possibly because its highly interactive and immersive nature, the medium has started to also be embraced for educational, health care, serious simulations, and military purposes.

As a player and game designer, I recognize that the medium of video games has great potential for creating meaningful experiences. As a researcher, I am exploring how games can be used as a tool for health. Games support and encourage emergent experiences, which can be extremely powerful because of how personal these can be. As an artist and game designer, I am constantly trying to understand how to better create interactive experiences for the player. Creating a virtual environment where players can be immersed and express themselves through the game’s mechanics and rules while being actively part of the story by “co-writing” it through their choices is one of the aspects that interest me most as a designer.

The key area of exploration in this thesis is the role that virtual reality (VR) and game design are tools that can aid and motivate people with and without arthritis to move in a safe and controlled way. The primary contribution of the thesis is the design and evaluation of Lumapath. Lumapath is a VR game I designed that creates a safe environment for users to be immersed and physically move in. The main goal of the game is to increase a user’s range of motion (RoM) and provide a risk-free environment for aerobic and stretching movements. Risk-free here is defined in terms of providing ways to interact in the game that do not damage joints. For instance, I avoided interactions that require quick reactions which motivate fast physical movements that might be dangerous for the player. The design process and user study results will be discussed in future chapters.
For the purposes of this thesis, I will be considering VR as immersive experiences where users wear a VR Headset / Head-mounted Display (HMD) that displays stereoscopic images and Motion Controllers in each hand for input and tactile feedback. “Lighthouse” cameras positioned around the area where the user stands track the user’s head and hands position in space.

1.1. WHO IS PLAYING?

According to the The Entertainment Software Association report “Essential Facts About the Computer and Video Game Industry” released in April 2017, 67% of US households own a device that is used to play video games. The average video gamer is 35 years old, and players aged 18+ represent about 73% of all current gamers. This information breaks the stereotype that games are primarily for kids.

Figure 1.1 Video gamer age groups

Even though the aging gamer population – defined as players 50+ years old – is quite large, there is very little content being produced that focuses on this target
audience, especially for female gamers. The reasons for this are unclear. Reasons might range, for example, from the stereotype that people who are over 50 years old do not like or are not video gamers to the fact that those who produce video games tend to be young males. Another reason might be the special amount of attention that is needed to design and develop for this aging demographic. Aging involves an inevitable number of restrictions to the human body, physically and also mentally. Performing activities that require physical dexterity or memory, for instance, can become harder to accomplish (Vasconcelos, Silva, Caseiro, Nunes, & Teixeira, 2012) or simply require longer response times.

Nevertheless, our aging population is growing. The United Nations Department of Economic and Social Affairs (DESA) estimates that the number of people over 60 years will increase from 962 million in 2017 to approximately 2.1 billion by 2050. Expressed as a percentage of the world population, these numbers currently represent 13% of the global population (2017), and are estimated to grow to about 20% in 2050 (UNITED NATIONS, 2017).

With this in mind, the number of people aged 50+ who may play video games will most likely grow in the next couple of years. Because of this possible growing demand, developing proper experiences with this group in mind will become even more important. Better understanding the limitations, preferences and motivations of this age group to design digital games are the objectives of this thesis. Digital games have the potential to become tools to assist and motivate the elderly to physically and mentally exercise, and as a consequence, improve their QoL by preventing or forestalling diseases (Chen, Chiang, Liu, & Chang, 2012).

The research literature shows that virtual reality environments can be an effective tool for motivating movement in users in a number of ways, from helping the elderly with balance training (Cho et al, 2014), increasing balance confidence and decreasing the risk of falls among community-dwelling women (Singh et al., 2012) to helping stimulate memory, improve motor coordination and exercise cognition (Buiza et al., 2009) and for motivating physical activity in both kids and adults (Finkelstein et al., 2011). Therefore, it’s clear that, when appropriately developed and designed with the correct audience in mind, VR systems can be a powerful tool for health. However, at present, there is very
little research that focuses on designing VR systems for this age group and also for people with rheumatoid or osteoarthritis.

1.2. WHAT IS ARTHRITIS?

Arthritis is a term often used to describe a disorder that involves stiff and painful joints, and decreases the RoM of joints. There are many kinds of arthritis but the two most common forms are osteoarthritis and rheumatoid arthritis. Osteoarthritis (OA) usually occurs with ageing in about 3.8% of the population, and can affect fingers, knees, and hips. Rheumatoid arthritis (RA) is an autoimmune disorder in about 0.24% of the population and often affects the hands and feet (NIAMS 2014)(March, L et al., 2014). In the U.S., 20% of adults have some kind of doctor-diagnosed arthritis (CDC 2015).

In general, studies have shown that physical exercise or movement of the affected joint can noticeably improve long-term pain relief. Furthermore, exercise of the arthritic joint is encouraged to maintain the health of the particular joint, the overall body of the person, and delay the need for surgical intervention in advanced cases (Fransen, M 2001). Regular and moderate activity is one of the best ways to ease pain, increase mobility, and overcome the limitations of arthritis. That said, it is possible to damage affected joints by overuse.

What I focused on when designing Lumapath was the stiffness and loss of RoM that results from arthritis. In this thesis, I will show how game design and VR may help with increasing the QoL of older adults through an interactive virtual environment that motivates physical movement, specifically focused on RoM.
1.3. WHAT IS LUMAPATH?

*Lumapath* is a VR system that uses HTC Vive, a stereoscopic VR headset that comes with handheld controllers, to track the user’s position in space, including their arm and hand gestures. The system is designed to create a safe virtual environment for users to be immersed in and work on their RoM. “Safe” is defined here as a virtual environment that takes the target player’s physical limitations in consideration to create an experience that will not motivate players to perform possible dangerous physical movements. Players travel to different planets in search of rare plants and life forms while operating a diverse set of interactions using their motion controllers. All user interactions are designed with the full RoM in mind, while at the same time keeping these actions as safe as possible.

The VR game uses aesthetic and mechanic immersion to motivate users to be in motion and is designed in a way to keep joint friction to a minimum, encouraging users to get into a flow state as soon as possible. This is important because players in a flow state are in an ideal balance of challenge and mastery, resulting in a more enjoyable experience. Guiding players through their first steps in the virtual environment (VE) was very important since most older adults might not have a lot, if any, experience with VEs. To accomplish that, I designed a tutorial area where players would hopefully learn everything they needed to experience the game, in less than 10 minutes.
By keeping track of the player’s performance throughout the different sessions, and by delivering this information back to players in charts and graphs, Lumapath tries to use player’s desire for mastery and the potential benefits of interacting with the game to keep them coming back for more.

The Literature Review in Chapter 2 is followed by chapters that articulate the Design approach, Development of Lumapath, its Evaluation, and the Conclusion.
Chapter 2.

LITERATURE REVIEW

This chapter is broken up into 2 main topics. In the first, virtual environments and aging, I discuss what previous studies were conducted using digital games in their several different forms as tools for health. In Previous Work, the second part, I focus on specific VR and non VR works that were created for users to practice their physical and psychological capabilities. Here, I analyze the VEs and point out where I think they succeed and where they fail.

2.1. VIRTUAL ENVIRONMENTS AND AGING

Keeping the body physically and mentally active is important for a healthier quality of life (QoL). As a person ages, this may become more challenging because of the changes that aging brings. For example, changes in motor, cognitive and psychological skills that affect the person’s perception and visual abilities are common aspects of the aging process (Charness, N, 2009). Moreover, activities that may need physical dexterity – like quickly pressing buttons on a controller or reacting to fast visual cues – might become more difficult to perform by aging populations (Vasconcelos, A, 2012). Memory, especially short-term memory, and attention are also affected (Czaja 2009), sometimes profoundly so. Such changes not only affect how a player uses VR, but also affects how they learn the conventions of VR games. Thus, when teaching players about new functionalities in a virtual environment – like how something might work, what symbols in the game world mean, or what enemies look like compared to allies – extra efforts such as teaching things multiple times are necessary to make sure the target players will have enough time to learn them. Such limitations must be considered when designing virtual environments, since they can completely change how this demographic will interact with the digital systems compared to a younger or healthier population.

Many studies show the positive health effects of virtual environments for older adults, not only physically, but also mentally. The repetitiveness of games that has players quickly reacting to visual and auditory cues for long periods of time while
mastering a particular skill in the virtual environment can, for example, improve the motor coordination of older adults (Ijsselsteijn 2007). These virtual environments can be a good source of fun and mental stimulation for older adults, while heightening their self-esteem through game rewards, constant positive feedback and a sense of mastery. In a study with 22 participants aged 69 to 90, for instance, researchers found that participants who played Super Tetris 5 hours a week for 5 weeks showed a significant improvement in reaction time to tasks and also reported a higher self-esteem and emotional well-being (Goldstein 1997). Benefits such as these can happen even in situations where players have moderate physical and mental limitations.

To counter the aging-related decline in speech processing, researchers developed HiFi, a game to boost the functions of the ageing brain. The game was tested with a group of 95 healthy older adults with an average age of 80 years old. The first group played the game for an hour each day for 8 weeks, while the second group spent the same time watching lectures on their computers. The third group didn’t change their routines. The group that played the game increased their scores on a standardized test of memory and attention by an average of 50% more points compared to the other two groups. According to the researchers, this improvement could be compared to the performance of people 10 years younger than the participants (Miller, G. 2005).

In a study conducted by Weisman in 1983, fifty participants with an average age of 85 interacted with four video games. These games were modified by a programmer to make them more accessible to the target demographic of the study. Little Brick Out was a game that required moving a rectangular bar up and down the screen to deflect a ball so it bounced back to and hit one of the colored bricks on the other side of the screen. This game can be compared to kicking a ball towards a wall or a racket sport. Ribbet was a game about pressing a button at the right time so a frog would catch a butterfly with its tongue. Country Driver was a game about keeping the car on the road while avoiding obstacles and turns. Finally, Hangman was a game based on the traditional word game of guessing out what letters are supposed to be written on each of the blank spaces.
Initially, participants played the games in a private room, with only one staff member supervising them. However, the researcher quickly noticed that having these participants play in an open environment, with other participants cheering and helping them out, made the experience more enjoyable and meaningful for participants. A reason given for this was that the social aspect of games proved to be a big motivation for play, as other studies have shown. Sharing or even comparing achievements is something that can be incredibly rewarding for people, and if they feel rewarded by playing a game, they may continue to do so.

Some limitations were noticed by the researcher. For example, some participants had a harder time quickly turning a knob left or right in the Country Driver game, compared to just pressing a button. This makes it very clear that the input device can have a big influence on the overall experience, and not just on the actual game that is being played. Country Driver proved to have another problem, where the car came from the top of the screen and not the bottom. This created a weird conflict in the player’s head: normal real world driving is done with the driver moving forward, looking at obstacles ahead, but the game made players look at the bottom of the screen for obstacles, as if they were looking in their own direction. Another interesting thing that happened was that the Hangman game was the one participants liked least. Players
expressed their feelings towards it saying that “it made them look stupid” and a clear sense of anxiety and fear was perceivable in some participants (Weisman, 1985).

In my opinion this might have happened because, of the 4 games, *Hangman* was the most familiar to the participants. All had spent their lives using words to communicate with others, creating this sense of mastery, or at least an expectation to do well with words. When they failed in that game, players probably felt that they were failing more than just inside the virtual environment. All other games were abstract activities that the players were just learning for the first time, so their intrinsic expectations would probably be more realistic to the point that they would more readily accept falling in those cases.

Playing digital games require a combination of different efforts from the player, like remembering how to interact with the virtual environment through all the different input methods, understanding and adapting to the rules of this virtual world, and having to constantly make decisions based on all of the feedback that the game provides. Different game genres might exercise a certain skill more than others, but in all of them, players practice their memory, decision making, speed, and motor coordination. In action games, for example, players might train a lot of their hand-eye coordination while constantly making quick decisions. Strategy games are hypothesized to benefit supervisory skills and working memory since players have to take their time while making decisions that will impact the next couple of future moves (Zelinski 2009).

In a feasibility study testing a low-cost system using Kinect for rehabilitation of the impaired upper limb for stroke survivors, developed in conjunction with the physical therapist team at the University of Utah’s Rehabilitation and Wellness Clinic, a 46 year old female stroke survivor played the presented game for ten days. The game required her to move her impaired arm by sliding it on top of a transparent-like screen that was placed facing up on a desk. Even though this setup limited the participant’s movement by mainly focusing on horizontal movements, it set boundaries for the experience, making it a safe interaction. The participant’s score increased considerably over the ten days, but that might just have been a consequence of the player getting used to the virtual environment, and not necessarily because they were physically getting better. In their post-test survey, the participant did acknowledge interest in using a similar system at home every day (Pastor 2012). Even though the game that was designed for this
study was extremely simple, this at least shows that virtual environments can be more entertaining than traditional therapy, as many other research studies have demonstrated.

2.2. PREVIOUS WORK

*Wii Sports* is a Nintendo game that was released in 2006. Players use motion controllers to interact with a collection of mini games based on 5 different sports: tennis, bowling, golf, boxing and baseball. Each of the 5 mini games simplifies its respective sport down to a few basic movements that are performed using the motion controllers. This makes *Wii Sports* extremely simple to learn and play even by non-gamers. Moreover, the fact that the mini games are based on real sports increases the chances of player’s already having a basic understanding of the rules and concepts. This is likely one of the main reasons for its immense success as a commercial product, with Nintendo selling over 80+ million copies of the game.

The visuals are extremely simple and serve the purpose of giving the activities context. Virtual environments such as these try to imitate their real world counterparts as close as possible, and keep the information on the screen simple and understandable. If the player sees a simple tennis court with 2 characters holding rackets on each side of the court, they will expect to play tennis just like they would in real life. This is true for all mini games in *Wii Sports*. The visuals are there just to set up the basic context, never to get in the way of what the player expects.

The game also saves a player’s progress by keeping track of basic performance data like balance, speed and stamina. Based on this data, it displays a diagram comparing these stats between each other and also generates a “Wii Fitness Age” value which is used to keep track of the player’s overall performance. This way, players can see their progress over time, comparing how they might have performed a couple of days or weeks ago. This kind of “longitudinal tracking” likely helps motivate players to come back and play again and try to beat their past performances.
The ease of use and external motivations created by its game design made *Wii Sports* quite popular with older adults. Retirement community members in Lincolnshire, England, for example, with an average age of 77, were actively using *Wii Sports* not only to have fun, but to be physically active while socially engaged with their peers (IJsselsteijn, W et al, 2007).

In 2007, Nintendo released their next iteration of “games to play by moving” with the *Wii Fit*. This time, the game was clearly marketed as “exergames”, with 40 different exercises and even the ability to measure one’s body mass index and center of gravity by inputting height and age. It also allowed players to select their target weight, and the system would calculate how much weight loss was needed per week to reach their objective. *Wii Fit* was a game system designed for players who enjoy the digital aspect of games, but who are also concerned about their health.

The game experience of *Wii Fit* was very different not only because the *Wii* motion controllers were used, like in *Wii Sports*, but also because it included the new *Wii Balance Board*. This new input method allowed for the player’s weight, balance and feet positions to influence the game experience. Because of that, over 40 different exercises in 4 main categories were available for players.
In the balance category, players focused in their ability to shift their weight between the balance board, going from the tip of their toes to the back of their heels and from one feet to the other. Aerobic exercises used fast-paced repetitive movements like quickly shifting your weight on top of the balance board to simulate a hula-loop motion or stepping outside of the balance board and then back on top of it in a rhythm-like game. The yoga category had players repeating body stances and movements that were seen on the screen while the system checked their center of gravity to grade how well they were performing. Finally, muscle exercises enabled players to perform strength training-like activities.

In *Wii Fit*, much more data was collected from the player than the prior system, and users also had more control and options for seeing this data. The game allowed players to see individual days with its corresponding data, and to also compare data tracked between friends. By also adding body mass index and weight information, the system got a little bit closer to player’s real world lives. These updates to the dashboard system likely helped motivate players even further by giving more detailed and meaningful information based on their gameplay.
In a study with 36 women aged 56 and above, *Wii Fit* was used with the experimental group to test the effectiveness of *Wii Fit* as an alternative to traditional balance exercises to decrease risk and fear of fall. Participants in the experimental group ended up requiring less supervision from therapist assistants initially and later were also performing their exercises independently (Singh et al., 2012). This is probably because the system is constantly giving the user real time feedback regarding their performance. Also, since participants didn’t rely on the group therapy sessions conducted by a therapist, they had more flexibility regarding time to perform the exercises.

Another study with 32 participants aged between 65 and 80 using *Wii Fit* three times a week for eight weeks showed that their balance improved considerably compared to the control group that did not exercise at all during those same eight weeks (Cho et al., 2014). Exercise using the *Wii Fit* proved to be feasible, safe and efficacious according to a study with 16 hospitalized patients with hematologic malignancies aged 60 years and above. In the study, participants exercised for 20 minutes using the *Wii Fit* once a day, five times a week, from the start of chemotherapy until hospital discharge. The adherence rate was 66.5% (Tsuda et al., 2016).

Using these studies as reference, and the overall success of *Wii Fit* as a tool for exercising, its safe to say that virtual environments can be extremely effective when designed correctly. They not only motivate people to move in similar ways to regular exercises, they also create a personalised experience that can be played with very little supervision (again, when designed properly), are constantly giving feedback to the user through visual, tactile and auditory cues and make the whole physical activity process
more enjoyable and fun. These can also be designed in a way to have a social component as part of the experience, where players can compare scores, compete and even work together to achieve a goal.

Another game developed by Nintendo that I think is worth mentioning, even though it’s not related to physical exercises, is *Big Brain Academy*. Nintendo has released multiple versions of this franchise in different systems, but I will be focusing on the one released for Wii in 2007. *Big Brain Academy* is a game with several different activities that focus on training your brain. There are a total of fifteen different activities divided into five categories.

![Figure 2.5 Big Brain Academy compute activities](https://ign.com/article/2007/06/08/big-brain-academy-wii-degree-review)

“Visualize activities” focus on quickly seeing an image on screen and making decisions based on it. In one of the mini games, players have to complete an image by placing missing pieces while using a second image as reference. Another mini game has players completing the rails for a train to get to its destination by correctly picking from a list of rail tiles with different shapes. “Memorize activities” have players paying attention for a few seconds to some information on the screen, and then making decisions based on what they remember from that. One of the mini games is based on the simple “three cup game,” where a player places a small object inside one of the cups, shuffles the three cups around, and the observer needs to guess where the small object is. Another mini game is about remembering the order of a sequence of images or numbers, and
then recreating this order from what the observer remembers. “Analyze activities” are similar to the visualize ones as they also use a lot of visual perception, but here it goes a bit further by requiring players to either breakdown shapes into other smaller shapes, recognizing patterns and understanding three dimensional space. One of the mini games shows players 4 different images and then asks a question or makes a statement and players need to select the only image that fits the text requirement. “Compute activities” are focused in math problems. Players either have to select numbers in a specific order, add or remove numbers so that the sum of the remaining numbers add up to a specific value or count colored balls that are falling into a basket. Finally, “Identify activities” have players focusing in what the image they are seeing represents. One of the mini games slowly shows pieces of an image, and the player needs to pick from a list of 4 words what this image is. Another mini game is based on the whack-a-mole game and players need to whack the moles that are holding the correct images.

Figure 2.6 Big Brain Academy Dashboard
Screen Capture, Big Brain Academy: Wii Degree (Nintendo 2007) Retrieved February 03, 2018 from http://technocore1.blogspot.ca/2017/07/10-video-games-that-will-make-you.html

When playing any of these mini games, players have a time limit of 60 seconds, during which they need to complete as many questions as possible. Correctly answering a question will increase the difficulty and consequently the amounts of points that can be earned. Answering incorrectly will decrease the difficulty while the player also loses potential points. At the end of each activity, the player is rewarded with their score, which is displayed as how many grams their brain weighs for that particular activity category.
This information is tracked across all the different activities, and is displayed to the player individually, per activity, as a radar chart that compares their achievements in these 5 different categories.

Now, if these mental skills that were practiced using the system can be transferred to real world scenarios is still an open question. A study with 78 adults between the ages of 50 and 71 completed 20 one-hour training sessions with the Nintendo Wii’s Big Brain Academy game over the course of 1 month. In the next month, adults completed the same amount of hours per week, but this time read articles on 4 different topics. Cognitive and perceptual speed tests were made before and after each month of training, along with knowledge tests. Results show that a clear increase in performance with the Wii activities, but less improvement on the knowledge tests, and practice-related improvements in 60% of the ability tests. However, no significant transfer of training was noticed from the training sessions regarding cognitive and perceptual speed abilities (Ackerman et al, 2010).

Participants said they enjoyed the game activities more than the reading sessions, but at the same time, only 40% of the participants reported a potential interest in continuing to play after the study was over. There are a couple of factors that might have influenced that potential interest, like not owning the system and feeling the investment was not worth it based on the results. Maybe the lack of replayability was a problem, where participants felt they would eventually get bored of doing the same activities over and over again. Or the child-like visuals from the game might have turned off some of the them. But I feel that the important thing to see here is that, in general, participants enjoyed doing this activity. They consistently got better at it and some even considered doing it more. All of that comes from a piece of software that wasn’t designed for adults aged 50+ as their target players. So I wonder what could be done if these systems were designed with this aging population in mind, and what kind of benefits this could bring.

There is a clear pattern with the three Nintendo games that I mentioned: they are all extremely accessible to the general population by having clear menus, simple gameplay, and basic art style. Menus are simple with the minimum amount of options needed, and all of the text is big and easy to read. Most of the activities that players do can be related to something that they are used to (sports, body movements or just math
problems). The visual style is simple, to the point that it is almost generic, but never seems to get in the way. What you see is what is important, and everything extra is either de-saturated or is displayed with low contrast to serve as a frame to what players should be looking at. There is very little room, if any at all, to feel lost while playing these games. Players always know where to go if they are navigating the menus, and what to do if during one of the mini games. Activities are simple enough so that very few instructions are needed; this way, players can be playing as fast as possible and with fewer doubts about how the system works. On top of that, all games have a big focus on tracking players progress and displaying it back to them in interesting graphs and charts. This helps motivate players to keep playing while also giving the opportunity for them to subjectively create goals based on their performance and scores, thereby increasing the replayability of these games.

Another important aspect of these games is that they use the *Wii* motion controller. It functions very similarly to a TV remote, in which you point to a television screen and press buttons. The added bonus is that by pointing at the screen with the *Wii* motion controller, you have a mouse cursor-like hand that is used to interact with menus and object in the game. So even if a person is playing any of these games for the first time, the input methods are similar to other things that they might have used before, decreasing the learning curve. Also, all of these games use very few buttons for the interactions, mainly focusing on 1 or 2 buttons together with the capability of aiming at the screen.

But not everything was ideal. Because of the way the *Wii* motion controllers captured player’s hand movements, it didn’t take long before players found ways of tricking the system. The controllers did not track its position in space but had acceleration sensors. This way, if the player moved the controller to the side, the sensor would pick up horizontal acceleration and assume the kind of movement the player had made. This problem was extreme in cases where large RoM was used. In the Tennis game in *Wii Sports*, for example, players could just flick their wrist instead of doing a complete arm swing, and the sensors would still think the player was actually performing a swing. This led some players to trick the system and limit a lot of the body movements that were initially designed for the experience. In a physical rehab situation, for example, this could get out of hand.
Audioshield is a VR game released in 2016 for the HTC Vive where players have colored orbs thrown at them in the rhythm of the music, and have to use their left and right hand shields to block them. Orbs come in three different colors: orange orbs, blue orbs, and purple orbs that are a combination of the two other colors. Players’ left shield is colored blue and their right one is orange; that means that to defend a blue orb, players need to use their left hand, while orange orbs need to be blocked by their right hand. When purple orbs are thrown at the player, both hands need to be used at the same time to create a purple shield. To make things a bit more interesting, these orbs don’t always come in a straight line. Orbs might fly in the direction of the player as an individual orb, which has players aligning their hand position to the position of the orb for a quick half a second block. They might also come as a sequence of orbs forming a straight line, requiring players to block and hold that position for as long as necessary. Finally, they can come as long curved lines that makes players block at an initial position in space and then move their hands in a specific direction, following the line’s curve. Sometimes players are doing these movements with only one hand, quickly switching between hands, and also with both hands at the same time for the purple orbs.
**Audioshield** uses songs to determine the pattern of the orbs that come towards the player during gameplay. Songs can be used from SoundCloud, Youtube or even the player’s own music collection that is in their hard drive. This gives the game a lot of replayability, since each song will create a different experience. Every song keeps track of player’s score, misses, most consecutive hits, hit percentage, artistic expression, physical activity, and most powerful hit. These values are combined to give players a total score. To make use of this collected data, an online leaderboard for each song is available, encouraging and motivating players to replay songs not just for the fun, but to achieve a better rank. Since the game doesn’t use a pre-selected soundtrack, players can select pretty obscure songs, and as a result have leaderboards created where they are the only ones there. This is extremely interesting, since it creates a very personalised experience for the player. The idea is that they might be the only one in the world who used that song to play the game. If someone ends up actually using that same obscure song, it becomes a personal competition between a few players who don’t even know each other, but who share a love or interest for this particular song.

The game difficulty is based on two different variables: the tempo of the song that is being used to generate the colored orbs, and the actual difficulty selected in the game menu. This lets players customize their experience, avoiding weird situations where the game might become too hard or too easy, and where the player doesn’t have any control over that. However, there are limitations with not adjusting this difficulty automatically based on their performance, but making it based on variables that the players have to choose. One issue is that because the game doesn’t have a pre-selected soundtrack and literally any sound file can be used, there are occasions where “song1” in <normal difficulty> mode might be harder than “song2” in <hard difficulty> mode. At least at a first glance, this causes players to try one or two different difficulty settings for each new song they want to use until they find the ideal settings for them. Another problem is that it’s not quite clear how these difficulty settings affect your score and consequently your possible position on the leaderboards.

I feel **Audioshield** is an interesting example of a game that uses automated generation to try to create an infinite amount of content, potentially increasing replayability. However, because a preselected soundtrack is lacking, where the experience could have been manually designed for optimal player experience, the sequence of orbs that is generated by the game’s code based on a song sometimes isn’t
fun to play. Orbs might be generated out of sync, eliciting a weird feeling in the player since they are trying to be on beat with the song. The sequence of orbs generated sometimes doesn't have a good progression, making some parts harder while some parts are too easy. Arguably, these problems could perhaps be fixed by a more intelligent code that analyzed songs better and created more enjoyable experiences. But how much work would have to be done to get a good balance from the generated experiences? Maybe if the game had a better social aspect, replayability would not only come from the amount of content that the game has, but also from player-created situations.

*Audioshield* is an interesting example of how much body movement can be elicited by a virtual environment, but there are some major downsides because of its design when adults aged 50+ are considered as the target players. I feel the the most problematic aspect of the interaction is essentially part of the core of the game's design. It's a rhythm game that is made to be played, and consequently more enjoyable, with songs that have a higher tempo. This can create dangerous situations depending on the user's physical limitations since they will be distracted and immersed in the virtual environment and might try to do everything to hit all the orbs. Fast arm movements tend to be less precise compared to slow ones, so the player may unintentionally hit their hands or arms on a real world object. Not only that, but since players have to put both hands together to defend from purple orbs, there is also the chance of hitting themselves with the controllers. Another possible problem also results from the fast movements that are required to defend from all orbs: players might damage or hurt themselves through overstretching, overuse, and/or repetition, going over their own physical limitations since while playing they might be distracted enough to not feel their body ache. Because of these possible scenarios, *Audioshield* would probably not be a game that the elderly should be left to play alone, without any form of supervision. And even with supervision, the design of the game creates situations that can be dangerous for an older demographic.

*Tilt Brush* is a VR painting application released in 2016 by Google. It runs on the HTC Vive and Oculus Rift, using the HMD to look around the environment and two motion controllers as a tool box and a paintbrush. The virtual environment treats everything around the player as a canvas, so strokes of virtual paint can be generated in “the air” using the paintbrush to create three dimensional images. One of the hands has
the brush that is used to actually “paint” and the other hand has a tool box with many options like different colors, brush styles, clear canvas and different background environments. These virtual paintings can be saved to a gallery-like system that can be used to look at past paintings that have been done already. Users can literally watch every single brush stroke as when it was originally painted until the final piece was complete, or just press a button and skip to see the complete piece. This feature is extremely interesting because you can watch other players draw their own creations while walking around the canvas. Moreover, just the act of walking around is interesting when you have a three-dimensional painting all around you.

![Tilt Brush](http://store.steampowered.com/app/327140/Tilt_Brush/)

**Figure 2.8 Tilt Brush**

Screen capture, Tilt Brush (Google 2016) Retrieved February 05, 2018 from http://store.steampowered.com/app/327140/Tilt_Brush/

These creations can be shared online through the VR system and also through one of Google’s websites. This is generating a huge gallery of user-created three-dimensional digital pieces that can be seen from a normal computer screen or by walking into them using a VR setup. The amount of different pieces that are being created and stored in this digital gallery shows how much replayability this system potentially has, as long as players don’t run out of ideas. One of the things the system does that I feel helps users avoid not knowing what to do or not feeling like they have enough skill to complete something is by giving many different brush options that look
interesting enough on their own. This makes it extremely easy for players to create beautiful looking three-dimensional sketches with very little effort even when the user is not the most creative or artistic person.

I think *Tilt Brush* is an interesting example of giving a lot of freedom to the user to express themselves in a virtual environment. It sets no specific objectives or requirements so each user can take their time to do whatever they feel is comfortable for them. Thinking of an audience of adults aged 50+, I think this makes it a very powerful experience. The fact that there are no requirements made by the system for fast hand movements - like quickly hitting an orb for points or a timer that puts the player in some kind of pressure - lowers the chances of players getting hurt by overstretching or similar injuries. Users are motivated to move around so they can paint in different parts of the “canvas” while also constantly moving one of their arms to perform the brush strokes. One big limitation of the way the system works is that the hand that is not holding the paintbrush is not used as much, and has very little, if any, large RoM movements. Therefore, unless the player actually switches the controllers between their left and right hands, forcing them to perform the paint strokes with both hands using the same amount of movements, one of the arms will be disproportionately more active than the other.

From the games analyzed, it’s clear that simplicity in the design can be very effective. It’s a way of removing unnecessary layers that the player will have to learn, and getting straight into the experience that matters. Simplicity in the aesthetics also seems to make experiences smoother, avoiding extra visual pollution and creating less confusion on player’s perception of the game world. The input methods that players use to interact with the game world must also be as simple as possible, not only for dexterity and coordination reasons, but also to keep the amount of memorization needed to a minimum. When players use actual physical movement to interact with a game, it’s important to have enough control of the way this interaction happens to avoid the ability of players to trick the system. This is especially the case when the main objective of the game is motivating a specific type of physical movement. Part of this control comes from the technology used, but a lot also comes from the way the system is designed. The content of the game can motivate different reactions from players, so when they are using their body to play, it’s important to make sure these reactions will not put them in danger of hurting themselves. For an aging population, slower movements are preferred rather than fast-paced ones. The social aspects of play and player’s mastery also seem
to be good ways of motivating players to keep them coming back to the game for longer periods of time increasing replayability. This is extremely important for my game since players’ RoM would probably only see any significant benefits with long-term physical activity.

Outside of commercially-available VR games, exceptionally few VEs have been created for arthritis research. I suspect this may be because many VR research studies, such as an early VR study that tried to replicate Tai Chi, for example, attempt to very precisely track a player’s movements in space to replicate exercises that physiotherapists give to arthritis patients. Although there have been many advances in VR since its early phase in the 1990s, this is still an exceptionally difficult approach. Currently, motion capture systems would be needed, and those are still relatively expensive and require purpose-built environments that would be difficult to transfer to clinical or home environments. For this and other reasons, my design approach is not intended to replicate exercises that a physiotherapist would give to arthritis patients.
Chapter 3.

DESIGN APPROACH

This chapter provides an overview of what Lumapath was intended to be, including its many different layers. This chapter is the blueprint of the project or, in other words, the design intention.

3.1. GOAL

*Lumapath* was born from the need to create an interactive system that helps to motivate people with arthritis to physically move as much as possible, with a focus on RoM. With that in mind, the design would have to take into consideration that the users would probably have very little to no experience with virtual environments. Also, extra care with how much I could expect physically from these users was required, since many different physical limitations may result not only from arthritis, but also because of aging. Therefore, it was important to have as much control as possible of the player’s body movements, limiting the speed, range, and number of gestures performed. Finally, the aesthetic and game mechanics would have to help create enough motivation to keep these users interested in interacting with the system for longer periods of time, and not only single sessions. All of this made it clear that VR was the most appropriate medium to use for this project.

3.2. THE CONCEPT

Based on the main needs and objectives of the project, I started creating the concept of this game world. Where does the experience happen? What does it look like? What are the various things available for interaction in this game world? All of these questions not only had to be answered, but also had to work for the aging adult.

One of the most basic requirements of the game, other than it actually motivating physical movement, was of creating a game world that could afford multiple different environments for the player to explore. This was important in helping to give players enough content so that they wouldn’t get bored easily. Even though these different
environments didn’t need to also have different mechanics, the differences in aesthetics should be enough to give players a sense of new. With that in mind, the idea of travelling seemed to fit the needs of the project, and also seemed to cater to the aging adult players, since travelling and seeing new places seems to be something that humans enjoy doing.

Figure 3.1 *Lumapath*: Concepts for the ship (silhouettes)

With that concept set, the player suddenly became an adventurer, and now needed a means of travelling and exploring the game world. This is where the ship comes into play. Initially, ideas of having a simple ship that would travel the ocean were considered, as were flying planes, which would have made this travelling process faster. But actually, what caught my interest was hot air balloons. They serve the purpose of travelling just like the other “vehicles”, but at the same time have this magical feeling to them. However, hot air balloons were too small and simple to support all of the necessary interactions and different environments for the game.
Figure 3.2 *Lumapath*: Final ship concept

Naturally, zeppelins seemed like the next obvious choice, since they still maintain a bit of the magic of the hot air balloons while being much more flexible for the needs of the game. Several concept sketches were developed, like the ones in Figure 3.1. The more sketches we did, the more we liked the idea of a floating boat-like ship. It seemed to be familiar enough so that players could relate to it, but still feel magical so that it could better fit in the game world and its rules, while providing room for player’s imagination. It would also be big enough to fit the house-like environment that was needed for players to have a neutral place to go while travelling to different planets.

This house-like environment inside the ship was very important since it was supposed to be a neutral and familiar place for players. Different planets would already have mysterious and alien-like shapes, colors, and sounds. Because of that, some players might not like some of the planets’ environments because of aesthetic or personal reasons. To balance that, I felt a safe and neutral place that hopefully most players would enjoy was needed. To try and achieve this neutral place, I felt it should feel like home. This home environment was designed exactly like that, a home. The fact
that it was in an actual floating ship would be demonstrated by some of the objects and the views that players would have by looking out the windows from inside the ship.

![Figure 3.3 Lumapath: Ship interior (home)](image)

One of the main ways I felt would help to achieve this familiar home-like environment was by populating the space with relatable objects that people could find in their own homes. Comfy couches, picture frames, and books could help give the sense that someone lives in that space. It’s alive because someone lives there. There are objects left on top of tables, and everything is not perfectly aligned as if it was done by a robot. Imperfection is everywhere, and I felt that these little details would help make this space more human.

Another important aspect of this environment was that it actually hinted at some of the narrative of this world. Maps and tools used by someone that is exploring different places are clearly seen in this environment. Nothing is explicitly told to the player, but combined with what they would be doing while interacting with the game world, these hints should be enough to contextualize their purpose in this story. Hopefully, this would enable players to change their point of view from “someone lives here” to “I live here”, making this environment much more meaningful.
Several objects were created to give life to this environment, but some of them are actually interactable and important to the player’s experience. One of the objects that was created for players to interact with was a small radio. It was designed in a way to look like the old radios from the 70’s, with a knob that when turned changes the radio’s frequency. While turning the knob, when the frequency was not in any of the stations, a static noise was heard, an attempt to simulate how these radios worked in the past. The closer the player gets to one of the radio frequencies, the clearer the music from that particular station sounds. The purpose of the radio was not only to be a familiar object that players could relate to, but also as a way for them to customize their experience. Based on their personal preferences, they can change the frequency to one of the four different stations: jazz, opera, 1930’s songs, and modern ambient music.

Figure 3.4 Lumapath: Radio concept
Figure 3.5 *Lumapath*: Slot machine concepts

The slot machine idea arose from the need to create more risk-reward mechanics for the player. Everything else in the game would happen in a way that the players could expect. There was no surprise or randomness to the way they interact with the game world and how it responded back. But humans also seem to enjoy the thrill of having a chance to win something, even if it means that there is an equal or greater chance of losing. This can be seen in casinos, the lottery, and other games where it’s common to see humans gamble their money. I wanted to have something in the game that could elicit this thrill in players while also connecting to the currency system that was created. The slot machine would hopefully also be something familiar to players, helping the environment feel more relatable, whether players like the concept of gambling or not.
Many different concepts were created for the slot machine since I didn’t want it to look like a normal slot machine that could be found in any casino, but a machine that was custom-built for the purpose of transforming the currency that was collected by the player. This was important because it felt like it was actually part of the game world, and not just an external concept that was thrown in. Initially, the concept that was chosen was the one seen on Figure 3.6. It was implemented in the game for a couple of months. However, I was never 100% happy with how it felt inside the environment. The objects around it felt more familiar and gave the interior of the ship a house-like feeling. The slot machine just looked like an elaborate mechanical object that just didn’t fit in.

So, more concepts were created, now with the idea of using household objects to replicate the functions from the slot machine. The idea of cooking came into mind where you are literally getting ingredients and somehow transforming them into something else. You can cook, fry and freeze something, and the result is a different material with different texture and flavor. Based on how long these procedures take, the results may
vary, sometimes giving good results and sometimes even failing, as when you let your meat burn in the fry pan. This themes of familiar, household objects that have the ability to transform was the new essence of the slot machine. It became a combination of a fridge and a microwave, where you put the currency collected into the microwave, run the machine that has gambling-like mechanics, and it can give you good or bad results. The difference was that now it had a completely different aesthetic that would hopefully better fit the home environment while also disguising its gambling aspect. Unfortunately, because of time constraints, this new version of the slot machine could not be implemented in the actual game at this time.

Figure 3.7 *Lumapath*: Slot machine concept (microwave and fridge)

The other main environments players would be experiencing outside of the ship were the different planets. Since players would be travelling in the game using this flying ship, the idea flying to different planets instead of just travelling across the globe seemed
more interesting. This would hopefully help players’ imagination flourish with the possibilities of exploring the galaxy. But it was clear to me from the very start that the idea of falling into traditional sci-fi aesthetics should be avoided. I felt the futuristic aesthetics could limit the potential interest of players while a more traditional aesthetic based on boats and machines, with some hints of magic and mystery, could be more flexible. For example, if looking at a medieval setting, it’s possible to understand and relate to some aspects of that more primitive context. But when looking at a futuristic setting, things might feel too far away or even too alien-like to understand. If I avoided futuristic settings that seem too far away, and instead used one that was closer and more relatable to us now, conversely, I would probably be more limited by the player’s expectations of the current time. Also, it made more sense for me to teleport the player into a magical world than a world that was too similar to reality.

![Figure 3.8 Lumapath: Planet concepts](image)

In the planets that comprise *Lumapath*, players would be collecting the currency that would make the game system work. It had to be a currency that could be available in all of the different planets, no matter how it looked. Therefore, the idea of a natural resource found in the real world made sense. Mining came into mind, where you can find different materials in different parts of the world. These different materials can have different colors, shapes and values. Making gems the currency used in the game world made sense, since it worked with the concept of exploring planets, while also being something that every player should be able to relate to. I would also be able to play with the idea of magical gems as sources of energy, which is a theme easily found in books and movies. Gems could also have a specific shape and color, making them an easy symbol for players to understand.
Just like mining, harvesting plants was a concept that also fit in *Lumapath*’s game world. Different plants could be found in different planets, making these environments not only more interesting aesthetically, but also with more reasons for players to explore these spaces. The idea of collecting a plant and taking care of it is probably easily understood by most. Farming is something that has been part of human history for centuries, so even though it would have some magical aspects, it could hopefully still be relatable for players. Having a plant harvesting system would also help make the currency system with the gems more meaningful. This would be accomplished by the fact that players would have to spend gems that they collected to help keep the harvested plants alive.

![Figure 3.9 Lumapath: Plant concepts](image)

Here I articulated the ideas and concepts behind some of the main environments of and objects in *Lumapath*. Hopefully, it will make the reasons for why the game world looks and feels the way it does seem clearer. The process was obviously not as linear as discussed here, but more of a parallel process where multiple aspects of the game world were being created and designed at the same time. A change in one environment
could affect all the objects that were inside it, so a constant back-and-forth of iterations was common not only during the pre-production, but also during the actual development of the game.

### 3.3. THE HARDWARE

Since the hardware used would greatly influence what could be done with the project, it was one of the first things that was decided on. The HTC Vive was chosen as the hardware that would be used for interacting with the VR game. Its “room scale” setup allows users to move around in a small playable area of about 2 meters square, while still tracking their head and hand positions. This seemed to be the most obvious choice compared to the more limiting system provided by Oculus Rift. Vive’s headset also had a superior resolution compared to the Oculus HMD, making it less probable that users would feel motion sickness, or discomfort from the game’s visuals.

![HTC VIVE HMD and handheld motion controllers](image)

*Figure 3.10 HTC VIVE HMD and handheld motion controllers*
The Wii motion controller was clearly not an option right from the start, since its tracking system was too simple, and since the movements are based on an acceleration sensor and not the controller’s real position in space. As mentioned in the previous chapter, this could enable users to be able to trick the system by not necessarily performing the correct movements, but just flicking their wrists around to trigger the sensor. The Wii balance board, on the other hand, is an interesting tool, but unfortunately, because of the project’s main goal and time constraints, no prototype could be created using it as an input method. Kinect was also not considered from the start since its tracking technology can become unresponsive at times. It also requires ideal room lighting conditions and an ideal and limited distance of users to the sensor. All of these issues can greatly affect what data is being captured. In addition, compared to Vive’s motion controllers, the useful data that could be captured using the Kinect would be quite inferior in quality and precision.

3.4. PHYSICAL ACTIVITY

Because of the nature and limitation of the technology and the target player group, the kinds of movements that could be explored in the system fell into aerobic and balance types. Aerobic exercises are activities that increase breathing and heart rate, which keep one’s heart and circulatory system healthier and improves overall fitness (Rahnama et al., 2012). Balance exercises can help prevent falls, an issue common with older adults and normally attributed to lower limb and hips weakness (Singh et al., 2012).

Since encouraging users to physically move was the primary goal, all interactions were designed for players to use their arm and hand positions in space to complete tasks. Through its gameplay, Lumapath creates sets of tasks that the user needs to complete to progress in the overall experience. For designing the movement of these tasks, many different sources served as inspiration. Tai Chi, Yoga and rehabilitation exercises were used as a starting point. The objective with these tasks was to create as much cross-training as possible, which basically means exercising different parts of the user’s body at the same time, while achieving a target heart rate between 50-85% of their maximum heart rate (American Heart Association: Target Heart Rates, 2010). The tasks were also designed following the American College of Sports Medicine’s guidelines with a 15% warm-up, 70% exercise, and 15% cooldown times (American
College of Sports Medicine, 2000). One thing to consider though is that most of these tasks, or similar variations, could be done without VR technology; therefore, discovering what the technology could add to the experience, and designing with that in mind, was very important.

3.5. NARRATIVE

A narrative is the use of signs, or of a medium, that evokes in the mind of the recipient the image of a concrete world that evolves in time (Ryan 2005). It can also be considered as a chain of events in cause-effect relationships occurring in time and space (Bordwell & Thompson, 1997). Narrative is normally thought of as a product of reading a book, watching a movie, or listening to someone tell a story. But with the evolution of technology, the game medium has come close to the storytelling capabilities of other media, but with one big difference - affordances of interactivity.

In a Game Developers Conference (GDC), Deborah Hendersen talked about a study conducted inside the Microsoft Game Studio: they checked players’ prior game experiences, and how much they remembered from the story of that game (Hendersen, 2014). Participants had difficulty remembering “the plot” from beginning to end and often had only fragmented memories of the game’s narrative. In contrast to that, these same participants could recall almost double the amount of information about “the plot” of other narrative media. Surprisingly, game characters were consistently remembered, not necessarily for their role in “the plot” but because of specific traits and personalities of that character. Participants also remembered gameplay narratives, in other words, narratives that happened as a consequence of subjective interaction to the game system. This happened even for players who said that they played games mostly for the story. And the opposite is also true, where narrative provided context for players who said they ignored the story.

In the last couple of years, more and more games with different ways of telling stories have appeared in the market. In the first example, *The Last of Us*, has an episodic structure that uses heavy cinematography techniques, impeccable voice acting, and high production values. In the second example, *Gone Home*, a personal and delicate story is told through the environment and player exploration. *Dark Souls* creates a world that players get so immersed through its gameplay that the narrative is told with
every single action the player performs. *Undertale*, with its silly story and amazing cast of characters, turns upside down an entire genre and defies many assumptions that the game medium has. All of these games tell compelling stories using completely different methods to do so. The first game tries to replicate how movies tell stories creating a cinematic experience with realistic characters and visuals. The second tells its story through small fragments, as if the player was reading small notes left behind by someone who wanted to be heard. The third tells its story not through words, but by the player actually experiencing the game world while slowly creating their own story based on their actions. The last uses charismatic characters and the player’s choices to adjust how the story ends. This shows how flexible the game medium can be, and that understanding these methods is incredibly important for the evolution of the medium. By ignoring traditional methods, we are free to examine other ways of telling stories that might be more efficient for the game medium (Bizzocchi, 2007).

The idea with *Lumapath* was always to create a rich world for users to be interested enough to interact with, ideally multiple times. Nevertheless, since the most important aspect of the experience in this case was to keep players physically active, the narrative should never get in the way of this goal. Having just enough embedded narrative to set up a basic context for the overall experience, creating a starting point for the user’s imagination, should be enough. This way, users would have the freedom of creating their own stories through their interactions, which may help users to feel like the experience was more personalized and that the narrative was a result of their actions, thereby motivating them to come back for more. The main story that should be remembered from experiencing *Lumapath* is of a player’s physical progress through time.

With all that in mind, *Lumapath* was designed with no clear linear path for the narrative, but more of an exploration. After the game starts, no narrative is actually delivered to the users unless they interact with the system, and all possible narrative scenarios emerge as a direct result of their actions. The user can choose where to go, what to do and in what order. Each of these decisions would impact the experience by opening new possibilities and slowly crafting a personal story that could be completely different for each player. There is no predefined ending to the story. There are no specific narrative arcs or chapters. The story is about the player’s own experience of traveling to different planets while collecting enough energy to keep going.
3.6. IMMERSION

Immersion is one of the most powerful affordances of VR technology. The visual and sonic focus is on the virtual environment, where external visual stimuli are completely removed by the VR headset. The feeling of presence results from controlling your point of view by naturally moving your head around, while the feeling of agency comes from having your hand and arms represented in the virtual environment without the use of traditional interfaces or “translators” (gamepads, keyboards, mouse). These phenomena make VR a great source for immersive experiences. However, if I relied only on the novelty of the technology, the intensity of the immersion would rapidly fade away.

Immersion also needs to be a result of the content, and because of that, *Lumapath* was designed to afford as much of that as possible. To discuss this aspect of the project, I will break the game’s immersion into two different categories: aesthetic immersion (AI) and mechanic immersion (MI). In the aesthetic category, I will discuss everything the user sees and hears, and how that affects their experience. In the mechanic category, actions the user needs to take and how the game mechanics interact and rely on each other will be discussed. By breaking these two apart, I will be able to go into more detail and explain the struggles, user studies feedback, and design decisions for each.

3.6.1. AESTHETIC IMMERSION

Aesthetic Immersion (AI) is all about feeling inside the environment and being curious enough to look around and search for more. It is a result of the combination of visual, auditory, and tactile stimuli. Because of the technology used, the visual and auditory stimuli will have a bigger focus, and the tactile will only come from minor vibrations from the motion controllers.
To achieve AI, the main ship environment where users would be spending a lot of their time was designed to be visually appealing and interesting for aging adults, and at the same time, hopefully trigger nostalgic memories. The main objective with this environment was making it feel like home while still being more interesting and mysterious. The environment was populated with objects that could have been found in people’s homes during the ‘50s through the ‘90s, making them identifiable by the target player group. The more complicated objects that have specific purposes, like the slot machine and control center, were a mix of different relatable objects to keep the overall aesthetic grounded and away from a sci-fi theme.

Figure 3.11 *Lumapath*: Controller concepts
Multiple planets were created to give the users the possibility of traveling and seeing different places. They would each have a very distinct theme which would set a completely different mood for the user. Planets would be large environments where players would be able to explore, looking for secrets and new sights to see. These would create a bit of a contrast to the ship environment, having vast areas that players could feel like getting lost in.

3.6.2. MECHANIC IMMERSION

Mechanic Immersion (MI) is about being motivated enough to take action inside and with the virtual environment; it is how users feel a sense of agency.
To keep users interested in doing the tasks, a currency system was implemented: players would be rewarded with this currency by completing tasks, and then the currency could be spent in other parts of the experience. The currency earned from completing the tasks could be spent in a slot machine, in a music player, for feeding plants, for upgrading parts of the ship, and for traveling to different planets. This way, if players want to interact with the different objects available in the game world, they are motivated to perform the main tasks to acquire currency. The currency is not infinite since it needs to be spent to activate the different objects available in the game world. This helps avoid players ever having too much currency so that they wouldn’t need to perform the tasks anymore. Everything is within the user’s reach, as long as they complete the tasks. The slot machine was designed with the risk-reward idea in mind: users can gamble and try to get more currency as a result. The slot machine’s probability was adjusted so that in average, players win only half of the time they gamble. This way, they could feel the adrenaline of gambling, but would never get enough rewards so that they wouldn’t have to perform the tasks anymore. The music player was a way for users to customize their experience by choosing different soundtracks to play in the background while they interact with the game, influencing the aesthetic immersion. The plant harvesting system is a way for users to explore and try to find hidden secrets in the game. It also has a management element, where users have to take care of the plants they harvest once they are in their possession. “We only truly feel a sense of choice when we perceive the situation as providing intriguing or valued alternatives or options, ones that we can actually explore and realize rather than just imagine” (Rigby, S., Ryan, R 2011 p. 40).

3.7. COMPETENCE AND MOTIVATION

I’ll be discussing competence and motivation, but before starting, it is necessary to clearly define these concepts. I use the following definition of competence: “Competence refers to our innate desire to grow our abilities and gain mastery of new situations and challenges” (Rigby, S., Ryan, R 2011 p. 10). Taking into consideration that competence is a basic psychological need of the human being (Elliot, A., & Dweck, C 2005 p. 6), this need instigates behaviors that are targeted at achieving specific goals to satisfy this need of competence. This motivation can come as an intrinsic motivation,
like an individual’s basic need, or as an extrinsic motivation, where the environment plays an important role in directing behavior.

From the start, one of the main goals of *Lumapath* was for it to be a system that could motivate physical movement over the long term. Therefore, it was important that not a single use experience would feel fresh and interesting only for the first minutes, but that an experience could grasp and hold the user’s interest and motivate them to come back for more. That would be the only way for the game to be successful since the process of exercising and seeing results in a user’s well being and QoL would take time. Part of the design of *Lumapath* required thinking of ways to enable users be interested enough to do the actual tasks, but also to be motivated to run the system several days in a week and for as long as possible. In addition, the system had to be constantly testing for users’ competence. In this way, the game could be used to its full potential.

3.7.1. INTRINSIC MOTIVATION

Playing video games or simply the act of play is a good example of doing an activity based on intrinsic interests while searching for enjoyment and satisfaction. Importantly, *Lumapath*’s main goal was to, through this enjoyment, motivate physical activity. So while designing the experience, I had to constantly keep reminding myself that the enjoyment was just the medium where which the main objective would be achieved. Therefore, through its design, I had to slowly transform external motivations set by the system into intrinsic motivations that would carry on with the user after the system was turned off.

The main source of intrinsic motivation that was designed for *Lumapath* was the dashboard system. In it, users would have information about when they interacted with the system, how many tasks they completed, how successful they were, and how much they are progressing in the different possibilities of the game world. All this data would be shown to the user in a simple and clean way, using charts, graphs, and symbols, with as little text as possible. The information would be broken down into weeks, so users could easily notice how frequently they had been physically active in the game. The dashboard system would also have to be embedded in the narrative of the world, as an actual part of the user’s ship. This would help making it part of the game world and not
just a screen full of data that could feel out of place to the player, possibly breaking immersion.

Therefore, through the dashboard system, users could acknowledge their progress in time and create the necessary motivation to keep moving forward. The more users come back to the system and do the tasks, the better the results they would achieve, and that would in turn be shown in the dashboard system. In the end, the focus is on the player’s competence and physical progress. Even though the game can often give players a less than ideal feedback (fewer stars), it still can manage to keep the user immersed in the experience by feeding their competence expectations at the same time. “… about one’s present or future competencies that are based on past behavior. Expectations are thus informed by one’s experiences and thereby represent a person’s performance history” (Oettingen, G., & Hagenah, M. 2005 p. 648).

3.7.2. EXTRINSIC MOTIVATION

The whole experience of Lumapath happens inside the virtual environment. This game world was not only designed as a geographical location where things can happen, but it was also designed with players’ autonomy and competence in mind. It is the place where players constantly have their competence tested, while also being where players can explore and create their own narrative. Through aesthetic and mechanic immersion, users are motivated to be in and to explore the environment. Because of that, the virtual environment can function as a big source of extrinsic motivation and thus had to be designed properly to be as efficient as possible with the target player group.

Another source of extrinsic motivation comes from exploration of planets. When in the different planets, the user is constantly reminded that there can be something new right around the corner, and with each new area reached, many new challenges and possibilities are presented to the player. “It is the environment that motivates (or at least elicits and controls) creative behavior.” “After all, if one specific behavior is targeted, it will not be original for very long! It will only be original the first time it is displayed (Runco, M. 2005 p. 610). Planet exploration leads to finding the purple crystals, collectible plants, and new scenery viewpoints, all of which are separate sources of extrinsic motivation.
Tasks would reward users with gems that could be converted into energy inside the ship. Energy was the basic currency used for most of the interactions in the experience and is required for the users to progress and reach new areas. Tasks therefore become “... the motivation to do an activity primarily to achieve some extrinsic goal, such as a reward” (Runco, M. 2005 p. 613). This makes completing these movement-based tasks the core aspect of the experience, and all the other mechanics work as extrinsic motivators to support it. This repetitive loop of exploring and completing tasks not only is constantly testing players’ current competence and, adjusting the difficulty as needed, but it is also feeding their competence expectations.

3.7.3. COMPETENCE EXPECTATIONS VS. FANTASIES

By constantly testing players’ competence, giving positive or negative feedback based on their performance, and adjusting the difficulty settings when needed, players can build healthy competence expectations. These expectations are built not only through the immediate feedback of completing tasks, but also by their history, recorded and visible on the dashboard. According to Oettingen & Hagenah’s (2005 p. 648) theory, “... beliefs are based on successful performance in the past, on observational learning, and on persuasion by informed sources, they can be taken as a valid signal that behavioral investment will pay off in the future.” Thus, using the dashboard system, the game was designed to keep players’ competence expectations in check, thereby avoiding situations where “competence fantasies” may occur. Competence fantasies “... tempt the person to mentally enjoy desired competencies in the present moment, concealing the necessity to still realize them in actuality. Therefore, fantasizing about one’s future competencies should trigger little motivation to actually attain the mentally enjoyed abilities” (Oettingen, G., & Hagenah, M. 2005 p. 649). These fantasies can lead to false expectations - and, especially in the case of Lumapath, where a user’s physical capabilities are being tested - can become a huge problem. Increasing one’s physical capabilities is already a slow process, and having to increase them while experiencing arthritis pain is an effort Lumapath is intended to address. Therefore, its system needs to make sure to keep users’ expectations as realistic as possible, to avoid disappointment or any other kind of frustration that might lead to a user quitting.
3.8. MASTERY

A big part of the experience with *Lumapath* is for the user to keep track of their performance in each session. Keeping a record of how long they played, their average accuracy, how many gems were collected, and what new areas were discovered during each of the sessions would be part of the tracking system. With this tracked data, the player will be able to compare their own performance throughout the sessions and notice improvements. This can turn into an intrinsic motivator that implicitly encourages players to come back to the virtual environment, and can help with overall retention.

Since the target players could be extremely varied in their physical capabilities, *Lumapath* was designed to dynamically change its difficulty level by adjusting the speed, complexity, and number of repetitions for the tasks. This in effect personalizes the experience and ensures that less agile users could still have an enjoyable time with tasks that make sense for their capabilities. At the same time, it prevents advanced players from completely or too easily mastering the game, and consequently leaving the flow state because they become bored. For example, as the user explores the game world, new tasks are presented to them. New combinations of tasks with a different number of repetitions also shakes things up a bit. This may prevent players from becoming rigid and inflexible, where they might otherwise just repeat the same actions that have already been successful. Thus, what is created is a system that checks for players’ competence at every turn, but at the same time, gives players enough autonomy to express themselves.

*Lumapath* has no explicit fail states. The idea was never to actually punish users in any way. All results users can reach are a direct consequence of their performance. In this way, the game demonstrates that with patience, understanding patterns, and physical progress, players can complete any task or overcome any obstacle presented in the game world. To make sure that happens, the difficulty is adjusted for each user. This approach was taken because it relates to the idea of flow: “The motivation to persist in or return to the activity arises out of the experience itself. What happens next is responsive to what happened immediately before, within the interaction, rather than being dictated by a pre-existing intentional structure located within either the person or the environment” (Csikszentmihalyi, M. 2005 p. 603).
Chapter 4.

DEVELOPMENT

In this chapter I discuss the decisions made during the development of Lumapath and how user testing influenced the design of the project.

4.1. THE CORE

Lumapath started with the idea that people with arthritis would be using this system to motivate themselves to move and, as a consequence, work on their RoM. Because that was the most important aspect of the whole experience, the actual tasks – or exercises – that were going to be performed by the user were the first things to be designed. Taking into consideration the possibilities and also limitations of the hardware and, at the same time, the limitations of the target players, different kinds of movements needed to be considered. To make things clear, by movements I mean the possible hand, arm and torso actions that could be performed by a user while in the VR system. Because a player’s view of the real world was occluded by the VR HMD, I decided that RoM that involved leg and lower body movements were not movements that would ensure a player’s balance or safety.

The first thing I did was to take a look at VR experiences and other VEs that used some kind of body movement as an input method. I looked for interesting movements and then analysed them through a couple of different lenses.

1 - Was the movement motivating the user’s range of motion?

This was important because while there could be interesting and fun movements that would get users moving for long periods of time, they might not actually motivate a user’s RoM by really focusing on the full potential of joint movements.

2 - Was the movement appropriate for the target player’s physical limitations?

Here the possible physical limitations the user might have had to be considered. Was the movement requiring some kind of combination of actions that could be hard for
the target player to perform? Was the overall experience simple enough to make the movement worth the user's effort?

3 - Was the movement risk-free or a minimal risk?

Even if the actual base movement the user was performing seemed to be safe, was there any chance that it could somehow become dangerous? For example, the base movement could be slow and safe, but the game might eventually display a timer to the user, putting pressure on the user to perform things faster, forcing them to increase the speed of this movement suddenly, and thus not making it as safe as before.

4 - Could the movement be modular for increased replayability?

This means that the movement could be performed in different ways, reducing the repetitiveness of the task. Also, this made the development process easier because it would be faster to make variations of a base movement than to create several different ones from scratch.

5 - Could the movement be tracked so data could be collected and used to check improvements?

This would be used not only to motivate users by showing them their own performance data, but for clinicians to possibly have a better sense of what these users are actually doing inside the system, and giving them the tools to find patterns and physical weaknesses in these users.

6 - Was it doable from a development perspective?

With the amount of resources I had, the skill set that was available to me, and the amount of time in which this project had to be completed, was it possible to develop a system around this movement and maintain quality while reaching the main goals?

After checking these different experiences, I looked away from the digital and focused on movements people do in the real world: actions that are performed on people’s daily lives, and body movements that are motivated by objects and machines for recreational or even exercise purposes. I ended being drawn to Tai Chi because it’s an activity that seemed to have a slow and controlled essence, but at the same time
could be very challenging and rewarding. Moreover, based on studies done with aging adults, it can be successful in increasing balance, endurance and strength (Lan et al., 2000) (Hartman et al., 2000).

Therefore, the main movement for the system started out as an idea of using your hands to follow a floating object that moved in a predefined path. The user would be able to see the object and the path at all times, lowering the chances the user could do something dangerous. If they followed the object and path with the handheld controller, they would always be in a safe zone. The floating object could enable the path to be repeated multiple times, forcing users to repeat the movement. Different paths could be easily created, increasing the number of possible movements that would be performed by the user. Because of that, the idea of having different paths as part of a sequence seemed like an obvious way users would complete these tasks inside the system. Movement sequences could be comprised of different paths, and these sequences could be balanced or focused on specific types of movements. For example, paths could have a mix of movements that require the user to reach forward with their arms, to the sides, and down and up, while another sequence could focus on having users repeat more movements with their arms up.

Figure 4.1 Lumapath: Path Task
This mechanic seemed to fulfill all the prerequisites that I described earlier. Different paths could motivate different types of movements that involve joints; thus, it became just a matter of designing the right kinds of paths to motivate as much of the user’s RoM as possible. It also worked for the target players since the speed of the floating object could be adjusted accordingly to the user. Moreover, it was risk-free since the system would only visually motivate users to move in a predefined path that was designed to be inside the user’s ability, and the speed would slowly increase as the user’s performance improved. It was also modular, which meant that designing new paths and trying them inside the system was a quick process, which in turn enabled a lot of movement content to be quickly created. Next, getting data from these movements would be extremely easy since everything was based on this floating object and its different paths. The user’s accuracy would be checked and with that, the system could be programmed to assess how well the user is performing in different paths, and if it needed to adjust the speed for a better experience. Finally, this approach made sense from a development point of view since it was fast to create and test, quickly iterating if needed. In addition, the visuals that would have to be created for these different paths was very simple, again making the development relatively easy.

4.2. GAME WORLD

With the core mechanic figured out, it was time to create a world where everything would happen. I knew it would be important to create an interesting environment where users felt comfortable and interested in being a part of, but I had no idea that it would have such a big impact on the user’s experience. I discuss that in the study results.

Just like the main mechanic, the game world would have to be flexible enough to allow for as much replayability as possible. Therefore, having different environments for users to explore was extremely important because it would help keep the repetitive nature of exercising from becoming boring. These different environments would also allow users to have their favourites and to enjoy finding new places to explore. With this in mind, the idea of travelling through different planets in space seemed like a good fit. It provided a lot of flexibility with the different planets being the different environments where the experience happens. Moreover, because they are planets in space, they can be completely different visually and thematically from each other. This would help give a
fresh perspective on the same activities that the player was already doing before, while discovering this new unexplored planet. Three different planets were initially designed, but because of the amount of time available to create all the content, only one planet was actually developed. However, because of the way the game world would work, implementing new planets would be just a matter of creating the new assets—specific planets—and adding them to the game without having to worry about creating new ways of interacting with this new planet. It would just be the same interactions from the other planets, but with a different theme.

![Figure 4.2 Lumapath: Cacti Planet](image)

With the basics of these environments created, it was time to connect the movement mechanic to the actual game world, giving context to the tasks players were doing. Since players would be travelling in space exploring different planets, they would need to somehow power their ship, and this is where the main task comes in. On each planet, players find magical crystals that are activated by the players' movement. The magical crystal creates a "floating soul stone" that moves in a path that players follow with their arms and, depending on how well they perform, it rewards them with gems in different quantities. These gems are then gathered and used by the player to generate energy that powers all the different possible activities besides the actual tasks that are possible inside the game world. Because of this, performing the task became the most
important aspect of the experience. If players want to open new things in the game world, they would have to complete tasks to do so. And since the energy generated from these tasks is “spent” to activate other activities in the game world, the player never has an unlimited amount of energy to spend.

Figure 4.3 *Lumapath*: Ship environment

The ship was always an environment that had to feel like a safe place for the player. They could travel through different planets, from cold icy caverns to sunny warm desserts filled with cacti, but they would always have a home to go back to: the ship. Because of that, the ship needed to feel familiar while still having the mechanical machinery of a ship travelling in space. This influenced the size of the ship environment to be as small as possible, while still having all the interactions necessary. This proved to be a challenge. Since the ship wasn’t small enough for players to just move around in by walking in the real world playing area, it required players to use the teleport system to move around the environment. This brings us to the next big layer of the system, the way players move around the virtual environment.
4.3. LOCOMOTION

HTC Vive allows players to move around a predefined area while the cameras track the user’s HMD and motion controllers. For Lumapath this playing area was roughly 2 meters by 2 meters. Inside the virtual environment, if players ever got close to any of the borders, a blue gridded cage appears to indicate the limits of the playing area. This helps to give an idea to players of where they can actually walk to without hitting objects in the real world.

Figure 4.4 HTC VIVE Playing Area
Retrieved December 13, 2017 from https://support.steampowered.com/steamvr/HTC_Vive/

Unless the virtual environment is as small as the playing area, however, players must have a different way of moving so they can move farther distances that wouldn’t be possible just by walking. This is where the Teleport tool comes into play. With it, players can aim at a location that is farther away from them, and they will be instantly teleported to that new location, having the playing area now centered on that new point. The teleportation method seemed to fit better to the system needs compared to other locomotion mechanics. Giving players control of moving their avatar using their
controllers, where their avatar moves in the virtual space without the player’s physical body moving can be very confusing to the brain, since player’s vision senses motion but their inner ears don’t. This moving method is known to cause motion sickness in a lot of players using VR, so it was discarded as an option very early in development.

Initially, the Teleport system could be activated in any flat surface on the floor of environments giving players a lot of flexibility to where they could move to. Basically if the ground was not obstructed by an object, players could teleport there. But this ended up being a bit too complicated for users and created room for a lot of confusing. Players could teleport into corners that didn’t necessarily add anything to their experience and because of the amount of freedom they had, it was easy for them to feel lost or to feel the need to interact with objects from several different positions. For example, if they tried interacting with an object and it didn’t work, since they controlled their position, they could feel that they might have teleported to the wrong place, or weren’t close enough to trigger the object. This added an unnecessary layer to the player’s experience, that like I said before, didn’t add much. The reasoning behind it being this way was that exploration was a big part of the game, so I felt that allowing the player to move around freely in the planets would help to create this interesting experience, but it ended up not working.

The Teleport system was tweaked: instead of using any flat unobstructed surface on the ground as a possible target for the player to move to, specific teleport points were determined and were placed in strategic locations that the player needed to go to. For the larger environments, this worked almost as trails in a forest, where the players knew they were always safe since they couldn’t ever get lost. Having these teleport points also helped direct the player’s experience, at least initially, enabling them go where they needed to go. For example, at the beginning of the experience inside the ship environment, only half of the teleport points are available. This helped direct players to objects that were important for them to see at that moment, and ignore the other objects that they could only interact with later. During user testing this proved to be very helpful, limiting the amount of time players wasted looking at parts of the environment that they could not interact with because they weren’t unlocked yet.

At this point, the placement of these teleport points became extremely important, since they were the only way for players to navigate the environments. In larger
environments like the planets, the teleport system worked fine since teleport points were far apart, but in a small environment like the ship, these teleport points would often feel too close to each other. This sometimes created confusion for the player since the wrong teleport point could be activated by mistake, which was caused by a combination of the control scheme not being intuitive enough and the placement of teleport points. Another issue is that players would be frustrated to see something in front of them but, when they try to reach it, it was actually just outside the playing area. This forced them to teleport to a different point and, from there, try to interact with the object. Because of these issues, the ship environment had to be tweaked a couple of times, slightly re-adjusting the position of objects so that the teleport points weren’t too close to each other and to avoid objects being just out of reach from the player.

![Figure 4.5 Lumapath: Teleport points (blue circles) inside the ship](image)

Another important aspect of the teleport system was how the Teleporting action adjusted to the playing area. Initially, the player’s position was used as a pivot to place the playing area in the teleport point, but this ended up creating situations where the playing area would collide with objects and walls like seen in Figure 4.6 A. This shouldn’t happen since it was not only breaking immersion, but it could also be dangerous as some players showed discomfort when they encountered overlapping objects and walls
during user tests. The teleport system was therefore tweaked to place the playing area in the center of the teleport point, no matter where the player was standing in the playing area (Figure 4.6 B). This worked for the planet environment where precise placement of the playing area wasn’t needed, but inside the ship, it ended being a challenge. Teleport points would have to be moved so that the playing area was in the correct position. This felt unintuitive since I wanted some of the teleport points to be right in front of the main objects that the player could interact with, and in some cases like the stairs and the crystal that triggered the path task, these teleport points were placed “on top” of the object. Because of these necessities, the teleport points ended up being only visual indicators of where the player could teleport to, but the actual position they teleported to was numerically inputted separately (Figure 4.6 C).
Another very important aspect of the playing area was getting the player to stand in an appropriate position to perform a path task. For most of the interactions, players were free to move around the playing area as they liked, but for the path task, they were required to stand in the center of that area. That requirement was to primarily prevent accidents since, if players are standing in the very center, they are the farthest away.
from all possible borders and objects in the real world. Another consequence of that requirement was that players would have to perform the movements the way they were designed. There was about half a meter of space that players could stand in around the very center of the playing area. If they were inside that space, the path task would work normally, but as soon as they left that central space, the system would lock during the path task, and would ask them to walk back to the center. This seemed to work since no accidents ever occurred during any of the user tests.

Figure 4.7 Lumapath: Teleport points (blue cylinders)

Telling the player where to stand, however, was a bit of a challenge. First of all, putting visual cues on the ground were normally not immediately seen by the player, especially if these cues were 1 or 2 meters away from them. This was solved by placing arrows pointing to the ground that were about 1 meter tall. With that, even if players were looking to the horizon or even looking up, part of the arrow would appear in their “peripheral” view and would call their attention. Another issue was how these visual cues should visually appear or look on the ground. Initially, a rectangular bull’s-eye kind of graphic was used, where the center of the bull’s-eye appeared in the center of the playing area, and it would spread out to the borders. There were 4 rectangular rings that
would light up if the player was standing in that position. However, this just added more visual pollution for the player, since the only thing that really mattered was if they were standing in the center; having these rings light up anywhere other than then the center was not giving meaningful information for the player. Thus, this bull’s-eye visual cue was completely removed; the only thing that remained was a circle in the center with feet icons on it. If the player was outside of that area, an arrow would appear pointing at it. If the player was inside the area, they could perform things normally.

Initially this center graphic remained visible even in places where the player didn’t necessarily have to be – in the center of the playing area. This was done just to give the player a clear reference of where the center was. The arrow wouldn’t show up if the player was away from the center, but the circular graphic was still visible on the floor. Several times during user tests, players would try to interact with objects that either weren’t interactable, or they were just interacting in the wrong way. They would look at the floor, notice they were away from the center of the playing area and would walk back to the center, expecting that then they would be able to interact with whatever they were trying to interact with. Therefore, this requirement, which they learned when doing the path task ended up influencing the rest of their experience as long as they saw the visual cue on the ground. This was fixed by removing the center visual cue from all places except the ones where players would be doing the path task. The only visual references they had of the playing area was a thin white rectangle on the floor that constantly showed the actual borders; the blue gridded wall would appear if they got too close to any of the borders.

Finally, one complication of using the teleport system was that to teleport, a visual line would come out from the tip of the controller, and the player used that line to point at places they wanted to move to. This created a little bit of confusion among some of the players because they thought they could aim at objects that they wanted to interact with, instead of having to move closer to and touch the objects with the controller. This negatively affected two main aspects of the experience: interacting with objects and locomotion.
4.4. INPUT

Now that the game world was established, the focus turned to developing the basic actions that the player would have to perform. They would use the motion controllers to move around the environment, to interact with objects, and to collect floating gems that were rewarded for completing tasks. All of those actions had to be performed by using the buttons available on Vive’s two handheld motion controllers. Based on initial tests that were conducted with team members and some external participants, the side buttons were not used since they didn’t feel very ergonomic. The buttons that were used were the TOP button (1), PAD button (2) and the TRIGGER button (3). A couple of different control schemes were tested throughout the development since players’ feedback was taken into consideration and tweaks were constantly being made to improve the user experience.

Figure 4.8 Input buttons on handheld controllers

The very first control scheme used the touch functionality of the PAD, turning it into four different “virtual” buttons that were triggered depending on the position of the
user’s finger on the PAD. Initially this seemed like the most obvious choice since all tools were accessible by pressing the PAD, and activating these tools was always achieved by the TRIGGER. In this control scheme the TOP button was not necessary, reducing the amount of finger movement the player would have to do. Unfortunately, this scheme ended up being too complicated for older adults since they would often select the wrong tool because their finger wasn’t exactly in the correct position on the PAD. In addition, since the PAD is just one big button on the controller, there was no tactile feedback differentiating which of the four virtual buttons they were actually touching, and the visual cues didn’t seem to be enough.

The second control scheme ignored the PAD’s touch functionality and only used it as a button. The Teleport tool was activated by either the PAD or TRIGGER on the right controller. The Vacuum tool was activated by either the PAD or TRIGGER on the left controller. The player could switch the tools between their right and left hands by pressing the TOP button. The Claw tool would automatically “prepare” when the player was closer than 15 cm from an interactable object, and when prepared, would be activated if the player pressed the PAD or TRIGGER button. The idea behind this control scheme was to give a lot of flexibility to the player by letting them use the PAD or TRIGGER for most interactions. This was especially important in the case of players who might have some kind of physical limitation related to their thumbs or index fingers, such as joint pain or swelling. However, because of all the flexibility, players would eventually get confused since the same button could do multiple things, depending on the context. Another thing that ended up being frustrating was the Claw tool that would be prepared automatically when a player was close to an interactable object. Several times players would assume they were close enough to interact with an object, press one of the buttons on the controller, and instead of triggering the object they wanted, would be teleported to a different location or would trigger the vacuum, depending on the tool that was currently active.
Moving away from the idea that activating the Claw tool would depend on how close it was to an interactable object, the third control scheme went back to having the three different tools be selected by button presses on the motion controllers. The Teleport tool was activated by either the PAD or TRIGGER on the right controller. The Vacuum tool was activated by either the PAD or TRIGGER on the left controller. This time, instead of switching tools between the the player’s right and left hands, the TOP button would switch between the Claw tool and the corresponding default tool of the hand. For example, pressing the TOP button on the right controller would switch between the Teleport tool and the Claw tool, where on the left controller, it would switch between the Vacuum tool and the Claw tool. This removed the option of players having to choose which hand they would want to use for the Teleport and Vacuum tools, but the hope was that it would make things simpler for the player. Compared to the previous control schemes, it was definitely an improvement since players were making fewer mistakes than before. Nevertheless, now players had to constantly move their thumbs from the PAD to the TOP button, forcing them to sometimes hold the controller in non-ergonomic ways. This constant PAD to TOP to PAD thumb movement proved to be extremely complicated for some of the older participants. Also, this version had the same problem as the previous control schemes, where the PAD and TRIGGER buttons could
perform different actions depending on the tool that was currently selected, making it impossible for players to connect an action to a specific button.

For the fourth and current version of the control scheme, I removed the flexibility of using multiple buttons for the same action by making the Teleport and Vacuum tools be activated by the right and left PADs respectively. The TRIGGER buttons on both controllers are used to interact with interactable objects. Now, the TOP button turns on or off a <help> mode that offers tips on surrounding objects that are close to the player. With this new control scheme, buttons always perform the same actions inside the game world, allowing players to rely on “muscle memory,” which in turn seems to make interactions smoother the longer players are inside the virtual environment. However, because there is less flexibility with the buttons, players who might not be able to use their thumbs or index fingers could be negatively affected, making it impossible for them to interact with the virtual environment with this control scheme.

So far, this seems to be the best overall control scheme for the target players. For players who have some kind of physical hand disability, additional options can be added at the beginning of the game to help customize the controls to meet their specific needs. With this version, a minority is clearly affected, but this cost is balanced by providing a better experience for most of the players. Further testing still needs to be conducted with this current control scheme.

4.5. TUTORIAL

Teaching the user how to interact with the virtual environment was extremely important, especially because a lot of people from this older demographic don’t have a lot of, if any, experience with digital games. But it wasn’t only about teaching players how this specific virtual environment worked, but also teaching them how to be inside a VR system. For purposes of safety, it was crucial to enable these users to get comfortable while having their vision blocked by the HMD.

In initial user tests, some participants would be very scared of walking around and hurting themselves, and that obviously affected their overall experience negatively. Some participants wouldn’t even walk around the playing area, since they were not aware that the system would track their physical movements. Some would only rotate
their torso if they had to look back, instead of just turning their whole body 180 degrees. Because of those situations, it was clear that before teaching the players about the game, I had to first teach them how to use the hardware. This added an extra layer to the development, but it was necessary since only by being comfortable with the hardware would the player be able to fully enjoy the content. Therefore, in the tutorial, which happens right as the game starts, the first thing that users do is to move their arms and press buttons for the first time. Then, pillars with buttons appear on both extremities of the playing area, where one of these pillars has a red flashing button. If players are not looking in the direction of that flashing button, after a couple of seconds, arrows appear in front of the user, pointing in the direction that they should look. Once players are facing the flashing button, they are motivated to walk towards the button and touch it with the controller. Text then appears with basic instructions pointing at the button to make this process as smooth as possible. Some players just intuitively moved towards the flashing button once they saw it, while others had to actually read the text before taking an action. Next, players would be taught how to teleport around the environment by again using their controllers. At this point, users would already feel more comfortable being inside the virtual environment, getting used to the size of the playing area, moving around that area, and using their controllers to interact with the virtual world.
After the initial hardware tutorial, players were taught how to perform the path task with a simplified and slower version of the ones they would find on the actual planet. They receive their first gems for completing the task and then are instructed to use the vacuum tool to collect them. At this point, players had done most of the basic interactions they would be performing over and over again during the experience. In addition, this tutorial area was separated into several small islands that players could only reach by teleporting. Initial user tests showed that it was common for players to forget some of the mechanics before even leaving the tutorial. That was because these mechanics were taught only once and not repeated until the end of the tutorial. Even though the tutorial would take only 3 minutes on average, that was enough time for players to forget. Therefore, tweaks to the tutorial were made where the red flashing button pillars, which made players move in the playing area and interact with an object via the controllers, was broken into two separate moments. Instead of having four pillars at the beginning and not having any again for the rest of the tutorial, two pillars were left at the beginning and two were placed halfway through the tutorial. This helped remind players to move and interact with object, which was something they were already taught a couple of seconds ago. Another thing that changed was the floating stones. Initially,
there were floating stones only after the player finished the path task, forcing players to learn how to use the vacuum tool less than 10 seconds from learning the path task. This seemed like too much new information in such a small time frame. The solution was to teach them the vacuum tool before they even reached the path task; this way, when players received the gems from completing the path task, they already knew how to interact with those objects. With these changes, players also had to teleport between many more islands than before, which helps them learn that mechanic.

In the current version of the tutorial, players have to go back and forth between the different game mechanics before even leaving the tutorial area. Based on the initial user tests and the actual study, this seemed to help a lot since most players went past the tutorial smoothly. One thing that still needs to be implemented in the tutorial is teaching the connect-the-dot task. With more user tests the tutorial can be tweaked to be even more effective.

4.6. CORE GAMEPLAY LOOP

Since encouraging the player to move was the main objective of this project, the path task had to be repeated multiple times by the player during their gameplay. On its own, the task would start feeling boring and repetitive, so a reward system that was tied to a gameplay loop was designed. Basically, how it worked was: the player performs the task; they receive gems based on their accuracy; these gems can be converted into energy inside the ship; this energy can be spent to activate different activities and unlock new parts of the experience. When the player runs out of energy, the player needs to perform the task again; then, the player repeats this loop until all activities have been completed, everything in the game has been unlocked, or they just get bored and leave to hopefully come back another day to repeat this loop a couple more times.
To make this work, different activities had to be implemented and players had to have things to unlock; otherwise, the energy that players were collecting was meaningless. The path task was already implemented and working, so the beginning of the loop was there already. Thus, a couple of activities were created to fit the ship environment and to add value to the energy they were collecting. The slot machine was one of the first activities that was designed. In it, players had the chance to gamble their energy into more energy, playing with the concept of randomized rewards. This activity was very interesting since many players enjoyed it a lot, feeling the thrill of gambling their hard worked energy. But at the same time, some players clearly voiced their negative opinion about the idea of gambling. They would in the end mention that they were pleased that they could choose not to use it since it was just an optional mechanic and not something they had to do as part of the core gameplay.

To also help motivate players to perform the path task, other than the fact that they were being rewarded with gems that convert into energy, a dashboard screen was designed to show them information based on their gameplay. The game would keep a daily track of how many minutes players performed the tasks, how much energy was collected, and their average accuracy. This information was displayed in a “today” tab and also in a week chart where players could compare their performance throughout the
different days of the week. The dashboard also displayed a ranking list that had players’ usernames with their total average accuracy. An interesting thing happened after the ranking system was implemented, where the programmer and I would compete for the best rank during play tests. Unfortunately, this dashboard system would be better judged with a longitudinal study, where players would have the chance to build a history with the game world. In a single session study where participants would probably never interact with the game again, the dashboard seemed to have lost a lot of its potential because most players ignored it completely.

![Figure 4.12 Lumapath: Dashboard](image)

The dashboard also had an extra functionality if a player spends energy on it. By doing so, the player could activate a lever that lowered a chalkboard in front of the dashboard display, turning that area into an opportunity for players to express their creativity. Players could use a virtual chalk to draw on this surface when it was in front of them. Based on user tests, this seemed to be a very simple but effective way for players to have fun, and at the same time, to help motivate them to move their arms around in space. Unfortunately, this couldn’t be used as a main task since players would end up using their dominant arm, completely ignoring the other one. With the dashboard, players could work on the RoM of one of their arms, but unless they consciously also used their non-dominant arm to draw, the physical exercise would be unbalanced. After
15 minutes, the battery that was activated by the energy spent would run out, and players would have to spend energy again to activate the chalkboard.

A small radio that played four different music styles was also implemented as an additional activity. In it, players could spend some of their energy to have the radio on for 15 minutes. While it was on, they used the radio’s knob to change frequencies and to search for one of the four “stations” that played jazz, opera, 30’s songs, and modern ambient music. The idea with these was to offer some variety for players so that hopefully they would enjoy at least one of them. Also, it gave players a sense of control and familiarity in the ship environment, judging from the way it got reactions like laughs, smiles, and comments on the music styles during user tests. This had no impact on a player’s progress other than just being a fun little way for them to spend some of their energy and to customize their experience a little bit.

Extra activities were designed but never implemented. A flying drone, for example, would be powered by the energy acquired, and could help give life to the environment, keeping the players company while also serving as a source of help since it could move in directions that players should be looking, and display relevant information to the player. The drone could also carry the radio when the player left the ship environment, taking the music that players activated inside the ship to other environments. Unfortunately, because of development constraints, it was never implemented.

Upgrades were also designed but not yet implemented because of time constraints. For instance, an upgrade system that could make the vacuum tool stronger so that gems farther away could be collected was designed. Another upgrade would increase the limit of gems that could be carried at once, so players could collect more gems before having to return to the ship. There are definitely more activities that could be implemented to use the energy acquired by doing the path task. Since the basics of the core loop are already working, adding new activities would require making sure that they would be balanced and would be worth the energy spent.
4.7. EXTRA TASK

With the initial player tests completed, it was clear that only having the path task could possibly make the experience too repetitive, so I started designing a second task to try to balance that. The idea of collecting plants was already present from the beginning, but initially, it was just an extra activity players could do. Converting it into the second task made sense, and transformed the plant collecting part of the game even more important for the player. When initially designing this second activity, I clearly wanted it to be the opposite of the path task. While the path task requires players to stand still and focus on performing movements accurately with their arms in the air, I wanted something for the second task that made players actually walk around the playing area while still working on their RoM somehow. Since this task would be connected to the plant harvesting mechanic in the game, I placed the plant in the middle of the playing area, and players would have to walk around it while connecting floating dots by using both controllers at the same time. These dots end up creating lines that eventually start looking like cages, playing a little bit with the concept of capturing something. This task ended up making players move around quite a bit in the playing area.
area, and because they had to connect these dots using both controllers at the same time, it turned out to be a great way of motivating players to stretch.

![Image of Lumapath: Harvested plants room](image)

**Figure 4.14 Lumapath: Harvested plants room**

However, since this task was implemented in the very end of development, proper instructions weren’t created in time for the user study. But even with no instructions, most players were still able to figure the task out pretty quickly. The visual cues that were used seemed to offer just enough information for the player to try to perform the task for the first time. Thus, after completing the first connection, players would have an “aha” moment and would continue until completion. The few participants who did have a little bit of trouble would instantly get it after they heard me say “try using both controllers at the same time”. Therefore, it was clear that with just a few basic instructions, this task would work out pretty well.
Chapter 5.

EVALUATION

5.1. STUDY

Twenty-eight people participated in the study (Female = 15, Male = 13, M = 37.63, SD = 18.89) ranging in age from 20 to 79. The study participants were separated in two groups: twenty participants were adults (aged 20 - 50) and eight participants were aging adults (aged 51+). Five of the aging adults reported some form of arthritis. Participants were recruited primarily through a recruitment poster that was sent to email newsletters for arthritis patients. All participants were told the study would require physical movement, and that they were not eligible to participate if they weren’t encouraged to do physical exercise by their physician or couldn’t stand on their feet for more than 10 minutes.

5.1.1. STUDY METHODOLOGY

This was a mixed-method study design with both a quantitative measurement survey and a qualitative semi-structured one-on-one interview that was audiotaped after obtaining consent from the participant. Quantitative data regarding the subject’s heart rate was captured by the system in real-time while the participant played. After gameplay, the participant was asked to fill out the Rating of Perceived Exertion (RPE) questionnaire. Lastly, I addressed participants’ interest in and willingness to play the game through a one-on-one interview.

5.1.2. STUDY INTERVENTION

The study tested Lumapath, a virtual reality game designed and developed in SFU’s Pain Studies Lab. The hardware used was the HTC VIVE HMD and its motion controllers. By putting on the HMD and holding a controller in each hand, participants were immersed in the virtual environment where broad movements were made using their arms and hands while they were standing. The game ran on a PC with Windows operating system.
The interaction began when participants followed a couple of verbal instructions so the system could be calibrated to their body dimensions. Next, they were introduced to the virtual environment and to its basic actions. After users were comfortable, they were teleported from the virtual tutorial area to the actual Lumapath game world. From this point onward, participants were free to choose where they wanted to go and what they wanted to do inside the system.

There were two different main tasks that participants performed while in the virtual environment. The first task required users to draws lines with different shapes in front of themselves, and required participants to follow the line’s movement with their controllers. These movements started with a slow speed and were adjusted based on the participant’s performance. The second task had users “connect the dots” in 3D space. Participants could take as long as they wanted since the system puts no pressure on them nor rewards them for completing it faster. However, the more accurate participants were, the faster the task was completed. Participants were allowed to stay in the virtual environment for up to 20 minutes, which enabled them to perform multiple tasks.

Lumapath uses aesthetic and mechanic immersion to motivate users to be in motion, and is designed with user retention in mind. It is also designed to keep friction to a minimum, getting users in a flow state as soon as possible, and guiding them through their first steps before letting them express themselves and make use of their agency in the system. By keeping track of the user’s performance throughout the different sessions, and delivering this information back to them in charts and graphs, the game tries to address the player’s desire for mastery and the potential benefits of interacting with the game to keep them coming back for more.

5.1.3. STUDY MEASUREMENT

This mixed-methods study design has both qualitative one-on-one interviews and quantitative evaluations. For quantitative data measurements, the participant’s heart rate was measured, and their Rating of Perceived Exertion (RPE) data was collected. Participant’s perceived physical exertion was documented using The Borg Rating of Perceived Exertion (RPE) questionnaire. The RPE is a subjective way of measuring one’s physical activity intensity level. With it, a good estimate of the actual heart rate
during exercise is acquired. The results from the questionnaire were compared to the Heart Rate data collected using Scosche’s Rhythm+ Heart Rate Monitor Armband that participants wore on their forearm during the VR study.

![Rhythm+ Heart Rate Monitor](https://www.scosche.com/blog/rhythm-app-support/)

**Figure 5.1 Rhythm+ Heart Rate Monitor**
Retrieved December 12, 2017 from https://www.scosche.com/blog/rhythm-app-support/

For the qualitative data collection, I conducted a one-on-one semi-structured interview after the game intervention. I audiotape the interviews and subsequently looked for patterns and themes.

### 5.1.4. STUDY PROCEDURES

The study took place in room # 2765, in the Pain Studies Lab on the Surrey Campus at Simon Fraser University. The whole study session lasted for approximately 40-50 minutes. Upon arrival at the lab, participants were briefly introduced to the study and the actions they were expected to take. Next, they were instructed to read and sign a consent form that described the study process, potential benefits, and participants’ rights. Participants were informed that they could ask me questions regarding the consent form and the study if needed.
Next, participants were orally introduced to the game, their age and gender were added to the system, and participants played Lumapath for about 20 minutes. After the gameplay, the participants removed the VR gear and were asked to sit and fill out the Perceived Exertion questionnaire. After that, I conducted a semi-structured one-on-one interview where I asked participants about their past experience playing digital games and Virtual Reality, and their experience playing Lumapath.

5.2. RESULTS

Here I’ll present and discuss my findings based on the HR data that was tracked and participant’s perceived exertion. Also, based on the interviews I did with participants, I’ll discuss some of the main themes that seemed to be recurrent and relevant to the system’s design and effectiveness.

5.2.1. HEART RATE AND PERCEIVED EXERTION

Unfortunately, the heart rate armband that was being used during the study wasn’t working properly, so many of the participant’s data were incomplete. The heart rate tracking would stop updating, resulting on HR data getting stuck and not changing any more. This would be random, having no specific time where this happened or specific action that triggered the problem. Because of this, it’s important for me to note that four of the twenty-eight participants didn’t have more than 1 minute of relevant tracked HR data, so their HR data was not considered. Also, twelve of the remaining twenty-four participants had more than one minute of data, but less than five minutes.
Ten of the twenty-four participants had an average HR above their 50% threshold of max HR. This means that on average they were in a light aerobic state while playing *Lumapath*. Six participants had their HR go above their 60% threshold at least once during the game. One participant had their HR go above their 70% threshold once during gameplay. It’s also important to note that all participants above 40 years of age had their average HR be above or very close to their 50% threshold.

These results confirm that the initial difficulty presented by the tasks is just enough to get aging adults into an aerobic state. But the main question is if the system would be able to adjust its difficulty to increase the average HR of not only the aging adults, but also of younger players. This would be important since there are aging adults who are very physically active, so the system would have to treat them just like they would probably treat a player 20 years younger. Unfortunately, this cannot be seen in the results presented here, since longer periods of play time would be required for the system to adjust itself to find the right balance to each specific player.
Nine participants had a perceived exertion lower than their actual average HR. Four participants had a perceived exertion of only 1 or 2 BPM higher than their average HR. The other eleven participants had a perceived exertion of 5 or more BPM compared to their average HR. If comparing the perceived exertion to the lowest and highest HR (Figure 5.2 Blue area) of participants, only 6 participants had a perceived HR above that area. Considering the fact that ten participants were above their 50% of max HR threshold, this means *Lumapath* was able to immerse players enough so that they were distracted from the amount of physical activity they were actually performing. The Borg scale values could be biased by the fact that participants knew this was a VR study related to physical exercise. No patterns were found regarding participant’s gender, experience with digital games or physical exercises.

### 5.2.2. EXPLORATION AND IMMERSION

Overall, participants reported that they “loved” exploring the environments and were visibly enthusiastic. Exploring the environment was the most mentioned aspect of the experience that participants said they liked most. Based on participants’ reports,
aesthetic immersion was deemed to be important to complement gameplay mechanics, and to give it more meaning and context.

“... I really liked the environments. I wish I could have walked a bit further cause at some point there was a wall.” (09)

“... the space is quite hard to see in real life, the desert and the cactus.” (13)

Exploration also appeared to be a crucial aspect that may have kept some players from feeling embarrassed or apologetic when they didn’t know how something worked since they felt they were discovering interactions just like they were discovering new areas while they played.

“I have control issues so not having any direction of what the task was or not knowing what I was supposed to do, but, like, I didn’t mind like, trying to figure it out so much, just exploring the environment, yeah.” (14)

One of the main "aha" moments of the experience was when players were in the cacti planet and then they saw the ship for the first time. Players would instantly start either mentioning how cool it was or questioning themselves if that was the ship they came from. It motivated most of the participants to teleport closer, or to explore more of the environment.

“I liked how you are in the ship and its up in the air and then you teleport down and you can see the whole thing.” (06)

“I like the exploring part, just like looking around, like looking up and seeing the ship, ‘ok I guess this is my ship’. I liked that a lot.” (09)

“... the environments were really cool. I think my favorite part was I like looking at all the environment like, 360 looking around. And then I didn’t even notice the ship was up in the air at one point and that was really cool too.” (12)
5.2.3. DISCOMFORT AND MOTION SICKNESS

No one reported motion sickness during the study, even participants who initially defined themselves as sensitive to the issue. This shows that VR experiences can be designed in ways to avoid motion sickness. I found that having static, clear geometric shapes around the player helped them feel grounded. Environment animations should be kept to a minimum since it can trick the brain into thinking the body is in movement, even though the player might be physically still. Also, having enough contrast in color values and hue helps to give players a clear visual reference of the space around them. Any avatar related movement that happens in the VE should be controlled or at least expected by the player.

Over half of the participants did mention that the HMD was too heavy and a possible cause for not seeing themselves playing the game for longer periods of time. Below are some participant's answers to the question I asked: if the player felt any discomfort or motion sickness.

“Only towards the end. It was not motion sickness, but my head felt a little heavy, I felt something in the back of the head, I was getting a little tired. (01)
“... no, I only feel the headset is, the headset is heavy and my eyes are, not the eye, the forehead is not comfortable because I make it tight, so after I take it out I have to massage it.” (04)

“No, just my nose.” (19)

“... no, and I do have a very sensitive stomach but I don’t think I ever felt that.” (21)

Also, if the tracking system at any moment had some kind of problem, either due to physical or software reasons, the virtual environment around the participant could slightly shake a bit.

“When I was in the virtual reality, when I move I don’t feel like I’m walking in our world cause sometimes when I’m walking, sometimes the space will be shifter a little bit and that’s not real, yeah, I can feel it. When I look up I sometimes feel a bit dizzy, I don’t know why, I think because of the headset, it is a bit heavy, so it changed my balance.” (11)

In addition to the weight of the HMD, another big limitation of the current hardware is the fact that small adjustments to the position of the HMD on the user’s face has great impact on how the rendered image is being focused. It was very common for participants to adjust the HMD multiple times during the experience because of its weight, and because the user’s physical movements resulted in the HMD moving. This was particularly complicated in participants who had to wear glasses, since the blurriness of the image being displayed in the HMD couldn’t be determined to be either the result of wrong positioning of the HMD, or because of the participant’s eye limitations, or a combination of both.

There were a couple of participants who had more pronounced physical limitations, like a knee replacement surgery or even vertigo, but no one mentioned that the system made them feel any kind of discomfort or that they were unsafe.

“... no, and I, I got to tell you I, I, I, ahm, suffer from vertigos, look at that, and didn’t cause me anything, I treating for a very long time.” (28)

5.2.4. INSTRUCTIONS

More than half of the participants missed having additional verbal instructions, or just being guided a little bit longer before being let loose to explore on their own. They would frequently report feeling lost and ashamed of not knowing what to do next. This
was varied and not specific to any age group, as both young and aging adults had similar problems.

“... I think you noticed I was just like switching places, and then I was like, what to do, what is happening, lack of instructions.” (08)

“... the tutorials are fine, but when I start to walk on my own I don’t know where I’m going to.” (11)

“... there were only a few things that were harder to understand like what to do in some areas, where to go when there were so many options like in the house.” (15)

“... It took a little while to discover that there were little hints to do things. I probably never got the feel of which buttons did what, although I expect that eventually that would have occurred to me.” (21)

This instruction problem is something that could have been influenced by the fact that participants knew they were being watched, so they might have also been uncomfortable by perceiving that they were being judged. Also, most studies are very detailed in what participants have to do, giving them a step-by-step list of instructions. Because this experience had much more room for exploration, I made it clear to each participant that I was going to avoid talking to them as much as possible in order to not influence their experience. It also seemed that some participants didn’t mind sometimes feeling lost because of the sense of exploration that the environment created. Discovering how the game worked seemed to players like it was part of their exploration.

5.2.5. JOINT LIMITATIONS

One interesting thing happened with one of the participants who had arthritis. During the path task, there was a specific arm movement that the participant could not perform with their right hand without having their left hand help. The participant voiced their surprise, stating they had no idea that they had that physical limitation. It’s interesting to note that even though the participant had arthritis, they were extremely active physically so the physical limitation was an even bigger surprise because of that.

Because of the way the tasks were designed, the game could be used to reveal physical joint limitations that older adults might have and weren’t aware of, or didn’t discover during their daily activities. I feel this might be the case since when consciously performing physical movements, if any resistance or pain is felt, the person will typically
adjust their movement to avoid it. But when the game explicitly asks the user to perform a certain movement, indicating where their hand should be at all times, if any joint limitation exists and is triggered by the movement, it will become extremely clear.

5.2.6. INPUT METHOD

Controllers and their input need to be as simple as possible. Context sensitive interactions might make things more complicated than they need to be. Less freedom might equal a smoother experience. This was a clear problem among the older participants, partially because of the physical dexterity that was required and also because it was necessary to memorize the controller inputs to perform specific actions inside the virtual environment.

“Sometimes I wanted to teleport like, click, click, and I was still in grabbing mode or whatever, like not being able to just, like having to look at my hands so oh yeah ok now I can jump that affected it, not that it mattered.” (09)

“They are really precise which is nice, which is very cool, clear as far as looking down at them. The reaction time was quick as far as changing the tools. It was just a matter of getting used to what did what, not bad for a short amount of time I guess.” (14)

“... maybe my hands are small or something, but I found the 3 buttons to be awkward so I had to keep changing my hand position.” (21)

When using controllers to interact with the virtual environment, it is important to keep in mind that precision is something that aging adults might have trouble with. For both tasks in Lumapath, there was a lot of room for players to interact with objects, and they did not need to be extremely precise with their hand position in space. However, interacting with the chalkboard proved to be complicated for most of the older participants, and some younger ones too. The level of precision needed to draw at the board was a little too much. For instance, having players keep a steady distance from the board while moving their arms vertically and horizontally proved to be difficult for some of the players, so the drawing would constantly be interrupted, which in turn frustrated some of the participants.

The tactile feedback of the controllers also helped players with immersion and functioned as cues for some of the interactions.
“... it's really cool... I'm holding something that I can create, like Iron Man like I don't know, virtual stuff... that was really cool.” (05)

“... I think I really like the vibration because it feels like touching something, holding something... the only thing I feel is real because it’s in my hand.” (11)

5.2.7. ENDURANCE

Overall, users stayed in the virtual environment for approximately 20 minutes. At the end, many would mention that the HMD was heavy, but wouldn't mention standing for the last 20 minutes as a problem. Based on the perceived exertion, participants felt it was, on average, light activity. This shows that the game managed to keep participants immersed enough to not notice the fatigue of standing and moving their arms around for at least 20 minutes. Participant 14 had a sore hand before the gameplay session started, but still managed to play the game for 31 minutes without mentioning her hand once.

“... my hand was hurting a bit at the beginning but the experience did not make it worse. It didn’t make it worse, it’s just tingling, so I don’t know if it’s from vibrating... it’s not unpleasant I can feel I did something. The responsiveness and the light touch on the controllers wasn’t a challenge for me.” (14)

Participants who defined themselves as “physically active” had an easier time with the movements in the virtual experience. Some even mentioned that the tasks were too boring because they were too slow and too easy to perform. Moreover, because the gameplay sessions were so short, there wasn’t enough time for the system to adapt to the difficulty based on a player’s performance, which was intended to balance the challenge to achieve a flow state.

“... it's kind of boring, maybe just because I move a lot daily so its really light for me.” (08)

One of the older participants mentioned being allowed to walk around as one of the reasons of being able to physically last longer inside the virtual environment. They thought that if they had to stand still in the same position, they would get tired faster. Some participants did mention their physical limitations affected the way they were interacting with the system. Nonetheless, because of the way the interactions were designed, no one mentioned actually being forced to do something that hurt themselves. They could always find a way to adjust and adapt according to their limitation.
“... yeah, I had difficulties stretching with my spine with the circles task. The circles were far apart, and also some were behind the cactus or something, (so) unless I wanted to glitch through the cactus, I had to kind of hug it. I didn’t know if that was part of the exercise.” (10)

5.3. LIMITATIONS

It’s important to consider some of the possible limitations of this study. Probably the limitation that most affected results was the amount of time that participants had to actually play the game. On average, participants played *Lumapath* for only 20 minutes including the 10-minute tutorial. This can be a big problem since participants are required to learn many new things, such as how to use the hardware to interact with the VE, and the several different rules and mechanics of this virtual world – all before even starting to freely experience the game. Because of that, the participants’ experience in the first 10 minutes could greatly vary, compared to the experience they could have in the last 10 minutes of the gameplay session. Participant 14 mentioned something that relates to this.

“I was a little bit frustrated ‘cause I guess I was thinking, for some assistance, like direction of what my goal was, so I kind of just went through it. But now that I saw the goal of getting the crystals and (that) I could move faster, and the more I got used to it the faster I moved.” (14)

“... understanding what I was doing at first, but then there were enough clues to kind of figure it out.” (25)

Another limitation related to time was the fact that participants were aware that they had a limited amount of time to interact with the game, like the quote below suggests.

“... am I going to really invest time figuring out the slot machine, or should I go out, or am I fucking up the experiment? If there was more time, I don't think I would mind at all figuring out things. I wish I could have like played it more to progress, see what happened.” (09)

In the quote above, the participant also mentioned that they were aware it was an experiment, which I think is the second main limitation of this study. I feel that the fact that all participants were aware that they were part of a study, inside a lab context with people analyzing them, definitely affected the way they interacted with the game. Some of the participants even compared this study with other studies the had been part of,
mentioning how in other studies, they had very detailed instructions of what to do and that someone was always directing them. Therefore, I feel that by knowing that they were not only testing a game but actually being part of a study, participants already came with assumptions and expectations based on prior experiences with other studies. This obviously greatly affects the data, specially since different studies have completely different methods and objectives.

Another possible limitation was the fact that in the title of the study, it was clear that the game was a system designed for motivating physical activity. This could lead to biased comments, especially from the older participants, since they could automatically add positive value to the game because of it’s designed purpose. Did the fact that they knew the game was a “serious game” influence how open they were to trying it? It’s hard to tell, even though it seemed like most older participants genuinely enjoyed the experience they had.

5.4. DISCUSSION

Based on my initial intentions with the design, and comparing them with the study results, all of the main aspects of the system succeeded. One of the main objectives of the game was always to motivate players to work on their joint RoM, and based on the way participants interacted with the game, it was clear that they were not only stretching their upper body, but also working on their balance to compensate for the upper body movements. No participant reported any problems during their gameplay session, and none were observed. Even when they mentioned some kind of physical limitation, the system never put them in actual danger of hurting themselves. Therefore, the objective of creating a safe virtual environment that motivates physical movement appears to have succeeded so far.

Using players’ feedback as reference it was clear that most of them were interested in and enjoyed playing the game. The mechanics seemed rewarding, but still challenging enough to make players feel a sense of achievement.

“... I liked realizing I learned something. It was an accomplishment.” (07)

“In the past I actually only experienced very simple things like when you are under the sea or flying in the sky. You can change your direction
and see different things. But this time I actually can control more. It’s cool to change the mode and do something I want to, and when I succeed, I feel a sense of achievement.” (11)

Many voiced an interest in wanting to see more of the experience, and that would result in playing for longer periods of time. The environment definitely helped create an interesting game world for players to explore and wonder. This is particularly important since the physical benefits of interacting with the game could only be seen by a frequent and long term use by the player.

“... first I was motivated by, like, the will to explore. I wanted to know the environment ... When I went upstairs, I was like, oh, ok, there are these cases, and I noticed one had the plant I captured, so I was like, oh, there must be more to it.” (16)

A major issue with VR is motion sickness. Based on the results with Lumapath, out of 28 participants, only one seemed to have experienced some degree of it. However, this player related it to situations that were created by the hardware, and not to the game itself. Therefore, I feel the design was also successful in not creating situations that could elicit motion sickness in the VE.

To conclude, players not only enjoyed the experience and being immersed in Lumapath’s game world no matter their age, but based on their HR data, ten of them were actually also in an aerobic state. This supports the idea that designing a VR system that motivates physical movement and increases players QoL is possible, particularly when care is taken to address all possible needs of the target player group.
Chapter 6.

CONCLUSION

Virtual Environments show a significant potential as tools not only of entertainment, but also as mental and physical stimulation for older adults that may help enhance their QoL. Designers create game worlds where players can immerse themselves while practicing their memory, decision-making, speed, and motor coordination. All of that, while increasing their self-esteem based on the achievements they earn, barriers they conquer and the progress that they make. Moreover, social bonds can be created through online interactions or through local peers, potentially enlarging a player’s social support. All of these factors have a big role in increasing the QoL in an aging population that is likely to double in the next 30 years.

Unfortunately, older adults are currently largely ignored by the main digital game market, where game studios primarily focus on younger adults and kids. This creates thousands of digital games that suffer from usability problems for the older population and also experiences that might not even interest them at all. Currently the digital games market is mostly under 50 years old: that explains why studios focus more of their resources researching and understanding this target group. But, as noted before, the older population is increasing, and most of the current youthful gamers will eventually become older gamer adults. Even though current gamers will reach an older age already having years of experience playing games, making it much easier for them to continue playing digital games – and even trying new technologies compared to an older population that did not grow with technology as part of their daily lives – they will still suffer from the several different limitations that ageing brings. These limitations will have to be considered by designers of these future digital experiences.

In chapter 4 of this thesis, I presented the design intentions of Lumapath, and explained how the feedback and considerations from older adults were used during the development to make the game more accessible and interesting. Results that show that this older group, even with physical limitations like arthritis, could enjoy and benefit from the gameplay just as much as a younger demographic were discussed in chapter 5. The overall awareness of physical activity in the VE was low, indicating that the system was
able to immerse users enough to the point that they wouldn’t notice that they were in an aerobic state. No accidents occurred, and except for some technical limitations from the HTC Vive hardware, users felt safe, comfortable and in control inside the virtual environment.

For the future, longitudinal tests would have to be conducted with *Lumapath* to measure the efficiency of all the implemented mechanics. Players should ideally interact with the game in their own home, so that the game’s ability to keep players interested could be really tested over time. There is still a lot of room for the game to be improved, so constant iteration would be needed taking into consideration the feedback that future users could provide.

With the brief experience I had developing *Lumapath* inside an academic context, probably the most important thing to take from this thesis, based on the results achieved and user feedback, is that design, art, and research need to work together to have a better chance of creating meaningful experiences. Taking the time to carefully design interactions that are interesting and fun, while also serving their main objectives, is fundamental for creating lasting experiences. However, it’s not only about what people do, but also what they see, hear and feel. Art must be taken seriously when designing any experience, since it can dramatically influence the user’s perception of the virtual environment they are in. Visuals and sounds can be just as important as the mechanics and systems manipulated by the user. Further, research must be conducted to validate and study what has already been done, but because of its scientific shackles that necessarily isolate factors from larger contexts, it needs the help of other areas, from experts who conduct research studies “in the wild,” to expertise from the arts and humanities. Otherwise, we will continue to see quality digital games being created only for the purpose of entertainment, while tons of academic experiments are so alienated from the real world that any data collected from them is, to say the least, extremely biased. As Frank Stella once said, “What you see is what you see”, no matter your intention.
References


### Appendix A.

#### Study material

<table>
<thead>
<tr>
<th>Level of Exertion</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>No exertion at all</td>
<td></td>
</tr>
<tr>
<td>Extremely light (7.5)</td>
<td></td>
</tr>
<tr>
<td>Very light</td>
<td>walking slowly at your own pace for some minutes</td>
</tr>
<tr>
<td>Light</td>
<td></td>
</tr>
<tr>
<td>Somewhat hard</td>
<td>still feels OK to continue with physical activity</td>
</tr>
<tr>
<td>Hard (heavy)</td>
<td></td>
</tr>
<tr>
<td>Very hard</td>
<td>have to push yourself to continue with physical activity</td>
</tr>
<tr>
<td>Extremely hard</td>
<td>most strenuous physical activity ever experienced</td>
</tr>
<tr>
<td>Maximal exertion</td>
<td></td>
</tr>
</tbody>
</table>

**Figure A.1 Borg Scale**
Q1: What is your relationship with games?

   Q1b: How many hours per week do you play games?

   Q: Where do you play?

   Q1b: Have you ever had a video game console?

   Q: How many?

   Q: Which?

   Q1b: Have you ever used VR?

Q2: Can you describe your experience?

   Q2b: What was your goal in the experience?

Q3. Did you have any difficulties while playing the game? If so, what were they?

Q4. Did you at any moment feel a discomfort like motion sickness or dizziness?

Q5. Based on your experience with AP (Lumapath);
   What did you like most?
   What did you like least?

   Q5b. How did the input method (motion controllers) influence your experience?

Q6. Is there anything else you would like to add?

Figure A.2 Semi-structured Interview Guide
Figure A.3 Complete HR data

Figure A.4 Incomplete HR data
Appendix B.

Concepts

Figure B.1 Tree/Waterfall Planet
Figure B.2 Cacti Planet
Figure B.3 Water Planet
Figure B.4 Dark Lava Planet
Figure B.5 Ship layout
Figure B.6 Ship layout
Figure B.7 Ship layout
Figure B.8 Ship layout
Figure B.9 Ship interior

Figure B.10 Ship interior
Figure B.11 Ship control area
Figure B.12 Ship control area
Figure B.13 Ship control area
Figure B.15 Plant room

Figure B.16 Plant room
Figure B.17 Energy conversion machine
Figure B.18 Ship mascot
Figure B.19 Ship mascot sketches
Figure B.20 Ship mascot sketches
Figure B.21 Ship mascot sketches
Figure B.22 Ship mascot sketches