

AALBORG UNIVERSITY COPENHAGEN

MASTER THESIS

Interaction Methods for Virtual Reality Installations in Museum Environments

An investigation into the usability and practicality of different VR interaction methods for a museum installation

Designing an Interactive Virtual Reality Installation for Greve Museum

Authors:

Simonas GARBACIAUSKAS
Tomas G. MOESGAARD
Mads H. NIELSEN

Supervisor:

Henrik SCHØNAU FOG

May 26, 2016



Semester: 10

Title:

Interaction Methods for Virtual Reality Installations in
Museum Environments

Aalborg University Copenhagen
Frederikskaj 12,
2450 København S, Denmark

Semester Coordinator:
Stefania Serafin
Secretary:
Lisbeth Nykjær

Project Period:
01/02/16 – 26/05/16

Semester Theme:
Master's Thesis

Supervisor(s):
Henrik Schønau Fog

Project group no.:
Group 1080

Members:
Simonas Garbaciauskas

Tomas G. Moesgaard

Mads H. Nielsen

Copies: 2

Pages: 89

Finished: 26/05/16

Abstract:

This project looks into how Virtual Reality (VR) creates exciting new avenues for museum installations with a specific emphasis on interaction methods. With technologies such as the HTC Vive and the Leap Motion it is now possible to create much more natural interaction in VR environments. Using GBL and Game Design research the authors used an iterative design process to create a VR experience that places one person as the cannoneer at Mosede Fort during World War One and up to several others as the map readers and range finders for the cannoneer. This product is supposed to be used as a teaching tool by Greve Museum at their Mosede Fort Exhibit after development is completed. The project experiment looked at the user experience of the application with the interaction method as the independent variable. Findings showed that while both the HTC Vive controllers and the Leap Motion gave the users a fun experience, most test participants found the Leap Motion more difficult to use.

Contents

Contents	3
1 Introduction	7
1.1 Motivation	8
1.2 Initial Problem Statement	8
2 Investigation	9
2.1 Introduction	9
2.2 State of the Art	9
2.2.1 VR Technology	9
2.2.2 Existing VR Museum Applications	13
2.2.3 Keep Talking and Nobody Explodes	15
2.3 Special considerations for museum installations	16
2.3.1 VR considerations	17
2.4 Discussion and Conclusion	18
3 Literature review	19
3.1 Introduction	19
3.2 Natural and Traditional control schemes	19
3.3 Virtual Body Ownership	21
3.4 Aesthetics and Design for Game-Based Learning	21
3.5 Theory of Fun for Game Design	26
3.5.1 Functionality of the Brain - Learning from patterns	26
3.5.2 Games as learning tool?	28
3.6 MDA: A Formal Approach to Game Design and Game Research	28
3.7 An Architectural Approach to Level Design	30
3.7.1 Operant Conditioning	30
3.7.2 Montessori Method	31
3.7.3 Constructivism	32
3.8 Discussion and Conclusion	33

4	Final Problem Statement	35
4.1	Delimitation	35
5	Methodology	37
5.1	Introduction	37
5.2	Research Methods	37
5.2.1	Testing User Experience	37
5.2.2	Observation	38
5.2.3	Analysis	38
5.2.4	Design of Product	38
6	Iterative Design and Testing Process	39
6.1	Requirements for Experiment and Prototype	39
6.2	Danish Learning Festival	41
6.2.1	Test overview	41
6.2.2	Conclusion	43
6.3	Singularity University Event	43
6.3.1	Test overview	43
6.3.2	Observations	44
6.3.3	Conclusion	44
6.4	Nordic Game Jam	44
6.4.1	Test overview	44
6.4.2	Observations	45
6.4.3	Conclusion	45
6.5	Mosedes Fort and AAU Demo Day	45
6.5.1	Test overview	45
6.5.2	Observations	47
6.5.3	Conclusion	48
7	Experimental Design	49
7.1	Introduction	49
7.2	Design of the Experiment	49
7.2.1	Design of Study	49
7.2.2	Hypothesis	50
7.2.3	Test Setup	51
7.2.4	Sampling	51
7.2.5	Test Procedure	51
7.2.6	Questionnaire	52
7.3	Design of Prototype	53
7.3.1	3D modeling	55
7.3.2	Unity implementation	57

7.3.3	Paper Tutorial	61
7.4	Experimental Protocol	61
7.4.1	Purpose of the Experiment	62
7.4.2	Materials and Equipment	62
7.4.3	Setup and Procedure	63
7.4.4	Methodology	63
7.4.5	Data Analysis	63
8	Final Experiment	64
8.1	Test setup and procedure	64
8.2	Observations	65
8.3	Interviews	65
9	Results	68
9.1	Introduction	68
9.2	Gender	69
9.2.1	AAU-CPH	69
9.2.2	UCC	69
9.3	Educational Background	70
9.3.1	AAU-CPH	70
9.3.2	UCC	70
9.4	Difficulty experience	71
9.4.1	AAU-CPH	71
9.4.2	UCC	72
9.5	User Experience	73
9.5.1	AAU-CPH	73
9.5.2	UCC	74
9.6	Overall Experience	75
9.6.1	AAU-CPH	75
9.6.2	UCC	75
9.7	Preferred Interaction Method	76
9.7.1	AAU-CPH	76
9.7.2	UCC	76
9.8	Frustration during the Experience	77
9.8.1	AAU-CPH	77
9.8.2	UCC	77
9.9	Statistical analysis	78
9.9.1	Hypotheses	78
9.9.2	Correlation	79
10	Findings	80

11 Discussion	83
11.1 Introduction	83
11.2 Methodology	83
11.3 The prototype	84
11.4 Practicality	84
11.5 The results	84
12 Conclusion	86
13 Future Aspects	87
13.1 Further academic work	87
13.2 Commercial possibilities	87
13.2.1 Historical Theme Parks	87
13.2.2 Independent Game	88
13.3 Potential of AR	88
Bibliography	89

Chapter 1

Introduction

With the recent release of the two mainstream Virtual Reality (VR) headsets - the Oculus Rift and HTC Vive, VR hardware is now finally at a point where it is widely available to the average consumer and is relatively affordable. This means that it is now easier than ever to employ Virtual Reality for various purposes other than games. One of these purposes are museum installations, as museums already have a history of using VR or similar technology to present information to attendees in more interesting and immersive ways. Before, these installations had to rely on technology that was either very primitive or very clunky, using an entire room with screens in the walls or using older VR headsets that were really big and heavy.

We believe that we can use the currently available consumer-grade VR technology to create an interesting and engaging museum installation. Along with using the previously mentioned HTC Vive VR headset, we will also attempt to employ the use of a natural control method in the form of the Leap Motion sensor and a semi-natural control method in the form of the HTC Vive motion controllers. This should help make the prototype be accessible to a wide audience. We will attempt to reach a conclusion on which interaction method might be most suited for a museum environment.

This report will present the research and investigation that lead to the design of an initial prototype, followed by an iterative design process that was used to reach the final design and implementation of the prototype. This report will also cover a number of experiments that were conducted using the mentioned prototype to compare the different VR interaction methods. The results of these experiments showed us that there is not a very significant difference between the user experience using the two methods, however the test showed that the participants generally

found the motion controllers easier to use.

1.1 Motivation

It is an exciting time to work in the Human-Computer Interaction (HCI) and Game-Based Learning (GBL) fields. As Medialogy students we get to work with some of the newest technologies and we have the know-how to work on the cutting edge.

Tomas and Simonas have been working with Virtual Reality since the first Oculus Rifts headsets was sent out to developers, conducting research in diegetic and non-diegetic mediation as well as interactive storytelling, all with a focus on learning. Mads has also been working with physical interaction in VR for measuring physical engagement, as well working on the feeling of presence of virtual body ownership using walking-in-place techniques. Simonas has had previous experience with trying to create a learning-based board game for university students. We have been working with Greve Museum to test out new ways of making museum installations and how to use VR technology to engage and teach museum guests. The VR market is booming and hopefully it will be possible to continue this work after our studies are over.

The VR developer community still has yet to come to a consensus regarding interactions methods. Some experiences still use traditional means of interaction, e.g. gamepads or keyboard, while others use more natural interaction methods, e.g. motion controllers or wearable sensors. This is a huge area of HCI research and we specifically want to look at the uses for different interaction methods for museum installations.

1.2 Initial Problem Statement

Based on the motivation for working with this project the following problem statement has been formed:

How do different interaction methods perform in Virtual Reality and what would be the most ideal choice, out of either natural or traditional control methods, for a VR museum installation?

Chapter 2

Investigation

2.1 Introduction

This section contains an overview and exploration of subjects that had to be considered in order to decide on the final design of the prototype and the experiment. This includes a look into some consumer-grade Virtual Reality display and control devices that had to be considered for the project. Several publicly available VR museum applications will also be reviewed and analyzed. Next is a short overview of a collaborative computer game "Keep Talking and Nobody Explodes" which was a big inspiration for the design of this project. Finally, this section will contain a short overview of certain considerations that had to be taken into account to make this project be a good fit as a museum installation.

2.2 State of the Art

This section covers different VR hardware and museum installations that exemplifies where the industry is today.

2.2.1 VR Technology

Samsung Gear VR

The Samsung Gear VR is a VR Head Mounted Display (HMD) that uses a smartphone as both a display and the hardware to run the VR applications. The headset

itself is only a shell that contains lenses and an inertial measurement unit. The phone is inserted into this shell so that the lenses are pointed at the screen. Located on the side of the headset are a back button and a touchpad, which allows the user to perform swiping motions to control the applications in various ways. The biggest advantage of this kind of interaction method is that it does not rely on any kind of outside controls and everything the user needs is right there on the headset. The touchpad allows for a number of different gestures that each control a different function. The main disadvantage in relation to this project is that the Gear VR headset has no 3d positional tracking and still relies on phone hardware, which severely limits the possibilities of an application. Another downside to this method is that the user might find their arm getting tired of holding it up to their head for an extended period of time.



Figure 2.1: *The Samsung Gear VR headset and a smartphone that would be placed inside of it. (Charara, 2015)*

HTC Vive

The HTC Vive is a VR headset that comes with two motion controllers that are tracked by two “Lighthouse” sensors. This allows for full 3d positional tracking of both controllers and the headset anywhere in the play area. This means that the player can freely and physically walk around the tracked area. The controllers have an analog “trigger” button, a circular trackpad, two side buttons and a menu button. The controllers can be used to both track the position of the user’s hands, e.g. for grabbing things in a VR environment, as well as be used as a pointer for menus and similar interfaces. The disadvantages of this method is that it might be quite cumbersome, as it requires a dedicated play area along with a computer that is capable of running VR applications and it requires setting up both the “lighthouse” stations and the controllers. It also has a cable that runs from the

headset to the computer and this can cause some inconveniences.



Figure 2.2: *The HTC Vive HMD being used along with its motion controllers. (Graham, 2015)*

Oculus Rift

The Oculus Rift was the first widely available consumer-grade VR HMD. It comes with a camera that allows for limited positional tracking of the headset. The current consumer version of the headset includes a traditional Xbox One gamepad that is used to control most games and applications created for the headset. The Oculus Touch motion controllers are only going to be available in late 2016. The gamepad would not be very suitable for the purpose of this project, as only people with previous gaming experience would be familiar with it, which might not be a very big portion of the intended audience. It requires a computer capable of running VR applications and, like the HTC Vive, the Oculus has a cable that runs from the headset to the computer.



Figure 2.3: *The Oculus Rift headset and the hardware that is included in the package. (Oculus, 2016)*

Leap Motion Sensor

The Leap Motion is a sensor device that uses two infrared (IR) cameras to track the position of a user's hands and fingers and use them as inputs. It can optionally be mounted onto the front of a VR headset and can then track a user's hands as they move them in front of their head. This allows them to interact with objects in the virtual environment in a very natural way. This makes it a very accessible method, since the user does not need to learn how to use any kind of controller and only needs to use natural hand gestures to perform actions. The main disadvantage is that even with the "Orion" update, released in February 2016, that massively improved the accuracy and speed of the hand and finger tracking, it still is not perfect. The sensor will still have trouble accurately tracking a user's hands in situations where part of the hand is occluded by something or when a user is doing very fast and sudden motions. This can sometimes be very disorienting in VR. The IR cameras inside the device also have a relatively low field of view, so they are only able to see the user's hands when they are directly in front of their face. Another disadvantage to this method is also the complete lack of any haptic feedback, which means that none of the actions the user performs in the virtual environment can make them feel any weight, friction or motion. This can be off-putting when they have to pick up a heavy object or do something like pulling a lever.



Figure 2.4: *The Leap Motion sensor being used to control a VR demo where the user is able to interact with objects in front of them using their hands (Forum, 2014).*

2.2.2 Existing VR Museum Applications

Gyeongju VR Museum

The Gyeongju VR Museum is a free application for the Samsung Gear VR headset that showcases the ancient city of Gyeongju in South Korea. The main screen in this application is an overview map which has small objects representing the different locations. The user can transport to these locations by looking at the object and tapping on the touchpad. They are then transported to another small environment that they can look and move around in. The movement is done by swiping on the touchpad, which can be very disorienting when swiping too fast, as it is very sensitive. The actions the user can do in these environments are very limited. They can interact with a small stand that pops up a window with some written information on the location or they can interact with some part of the environment which plays a short animation.



Figure 2.5: A scene from the Gyeongju VR Museum application. (Base, 2015)

Okyeonjunga 360 tour

The Okyeonjunga 360 tour is also a free application for the Samsung Gear VR headset that showcases the location where an old Korean scholar Ryu Seong-Ryong lived. The application has two modes – a guided tour mode and a free mode. The guided tour shows the user multiple 360 degrees photographs that they can look around in while a narrator talks about the history of that location. After that, the user is taken to a 3D re-creation of the house and is automatically moved around it to showcase different details in the environment while a narration gives information about those details. The movement is automatic and cannot be controlled by the user. After this section is done, the user can go to a 3D gallery that they can freely move around in that showcases various paintings of the era. The movement in this section works in the same way as it does in the Gyeongju VR Museum.



Figure 2.6: The Okyeonjunga VR Museum application. (VRPill, 2015)

VRMuseum.nl

VRMuseum is a free Windows application intended to be used with an Oculus Rift headset. This application contains a virtual art gallery with various paintings that are downloaded from an open data collection of a gallery in the Netherlands. This application can be controlled with a mouse and keyboard or with any PC compatible gamepad and it uses standard computer game controls. The user can move around, look at the paintings and get more information on them. They can also transport to three different environments and has a number of menu options, e.g. only displaying works of a certain artist in the gallery. The headset head tracking is not used for turning the in-game character and can be very disorienting for someone who is not used to virtual reality games or applications.



Figure 2.7: *The gallery environment of the VR Museum*

2.2.3 Keep Talking and Nobody Explodes

Keep Talking and Nobody Explodes is a computer game that heavily relies on player co-operation. One player is tasked with defusing a bomb that only they can see through a VR headset or a regular computer screen. Other players are given a bomb defusal manual that only they can read, however they cannot see the bomb themselves. The player with the bomb has to verbally describe it and its various modules to the other player(s), and they have to find the correct page in the manual that describes that module and gives instructions on how it can be defused. There is a timer that will cause the bomb to explode if it reaches zero and the bomb will also explode if the player makes too many mistakes. The game creates an interesting dynamic where all players have to always communicate and try to figure out the fastest way to relay information between each other.



Figure 2.8: *Keep Talking and Nobody Explodes* being played with a VR headset. (Buckley, 2015)

2.3 Special considerations for museum installations

When designing anything for public use it is very important to take any specific circumstances into consideration. Hornecker and Stifter (2006) released a paper where they talked about their experiences evaluating the Austrian Technical Museum in Vienna. They observed that people primarily come to museums in groups and want to be able to interact with installations in these groups.

“Installations with a physical setup that can host a small group, provides visibility and allows for handing over control or taking on different roles ... proved successful in supporting group experiences.” (Hornecker and Stifter, 2006)

These groups consist of many different combinations; families with small children, school classes, elderly with their grandchildren etc. Because of this it is important to make sure that the majority of this population can understand and use the installation.

People want to have both early success experiences with an installation and the possibility of being challenged through continued interaction. Hornecker and Stifter (2006) especially noticed that an installation with an oversized abacus and a screen that made the user solve different math problems were very popular and that small groups, 4-5 people, liked solving it together. Group members would take on different tasks and everybody would express happiness when they solved the challenge as a group.

Nathan Shedroff, a proponent of Experience Design, argues that productivity, creativity and communication are the basic human motivations and allowing the users to experience these leads to the most engaging interactive experiences (Shedroff, 1999).

Hornecker and Stifter noted in their observations that elderly people mostly avoided the computer terminals at the museum and preferred the exhibits with physical items. In contrast to this, children would skip these in search of games or other digital installations. Appealing to both sensibilities is important.

The points to take away from this are:

- Make usability considerations for all relevant age groups and include as big a section of the population as possible.
- The installation should be a group activity for small groups, 4-5 people.
- The activity should provide an initial success experience and then several levels of challenge.
- Design consideration for several age groups - children will normally look for games and digital exhibits and elderly people will look for physical exhibits.
- Novel input devices with computational augmentation are effective at arousing interest in people from all age groups.
- The installations should facilitate creativity, productivity and communication.

2.3.1 VR considerations

The nature of this specific project is virtual reality and not everybody might be comfortable using an HMD. Acknowledging this, it might be a good idea to let people interact with the installations in different capacities. This way they can find something to specialize in to help the group. This would further support the argument for having different roles in the group. After all, barring experimental VR multiplayer scenarios, only one person would be able to wear the headset at a time.

Motion Sickness in VR

It is important to remember that when you work with VR it is imperative that you follow certain rules regarding application stability and user movement. New

VR applications need to run at 90 frames per second (FPS), otherwise they feel unresponsive and might cause motion sickness in the user. It is a similar problem with user movement in the virtual environment. If the movement is unnatural or unexpected it can disorient the user and cause motion sickness. Virtual head movements should be kept as close to the user's real world head movements as possible. This can most notably be accomplished using full motion tracking of the headset.(UE4)

2.4 Discussion and Conclusion

The HTC Vive headset will be used along with its motion controllers and the Leap Motion sensor in this project. The headset allows for full natural player movement in 3D space and the Leap Motion and motion controllers can be made to function in similar ways. They will provide a good contrast between a very accessible and natural, but inaccurate method, and a less natural and more traditional, but accurate method that allows for more precise interaction.

A look into the state of some currently available VR applications revealed that a lot of them seem to put the visual aspect over interaction. They are often not much more than a virtual gallery that simply allows you to see things from around the world without having to go anywhere. This project will try to go in a different direction and put interaction as the main focus of the application. It will allow the user to get into the role of someone in a historic setting and hopefully cause them to become more engaged.

Another point to note is that museum visits are more often a group experience, so a VR installation should accommodate that. Some inspiration for reaching this goal comes from the examined "Keep Talking and Nobody Explodes" game. The application should engage a group of people by making the user with the HMD the focus point and having the other users help them in the task.

Chapter 3

Literature review

3.1 Introduction

This chapter is going to have reviews of different books and scientific articles relevant to the project. As the project is dealing with different interaction methods for VR in a museum installation, it is necessary to address game design, as the installation has game elements. It is also important to take note of previous research into natural and traditional control schemes. Virtual Body Ownership is also a subject that will be looked into in order to try to better understand how a user makes a connection with their virtual avatar in VR. There is a collaboration between the authors and Greve Museum, who are making different mathematical and physical education games in collaboration with schools. As the project partially functions as a math game, it is important to follow guidelines for Game-Based Learning. It should also be mentioned that, since it is a virtual reality installation, there is still not any design guide for how to design such an experience. This chapter will go through various books of Game Design to try to find some guidelines that would help with the design of the application.

3.2 Natural and Traditional control schemes

Previous research has been done in comparing different kinds of natural and traditional interaction methods in games and virtual reality applications. Nabiyouni et al. (2015) compared three different virtual reality interaction methods for moving around in a virtual environment. Those methods were:

- **Natural walking**, where the user simply had to walk around the environment and their position was tracked and represented in the virtual environment.
- **The Virtusphere device**, which is a large sphere that is mounted on supports that let it rotate in any direction as the user walks inside of it.
- **Traditional dual analog stick gamepad**, where the user has to tilt the control sticks to control their movement.

These control schemes were respectively classified as natural, semi-natural and non-natural. In the experiment, the participants were tasked with simply following a path that was indicated by a line visible in the virtual environment. The speed and accuracy of their movement was then evaluated and compared, along with questionnaires about which methods the participants found the easiest, least tiring and most fun. The results showed that both natural and non-natural control schemes allowed for significantly higher performance than the semi-natural control scheme and were reported as being much easier to understand and use. They also note that the semi-natural interaction method of their choice - the Virtusphere might have offered worse performance because of how cumbersome and complex it was to use compared to the other two methods.

Another similar test was carried out (McMahan et al., 2010) in which a similar comparison was made in Mario Kart, a racing game for the Nintendo Wii game console. The control schemes in this test consisted of two natural and two non-natural methods. The natural methods both made use of the Wii Remote controller and used the motions of rotating the entire controller to turn the in-game vehicle. The only difference being that in one case, the remote was inserted into an accessory that gave it the shape and appearance of a steering wheel. The non-natural methods made use of two traditional gamepads that were functionally identical by both using the analog sticks to control the steering of the in-game vehicle. These were only different in their physical form factors - a Wii Classic controller and a GameCube controller. Test participants were tasked with playing a time trial mode, where they were playing alone and trying to get the best lap time five times on two different courses, with the initial run being an introduction phase. The lap times were compared, along with a post-experiment questionnaire. The results showed that the non-natural interaction methods allowed for the best performance, while the natural methods were reported as being the most fun by the test participants.

The results of both of these experiments seem to show that while non-natural interaction methods usually lead to the highest performance in games or applications. On the other hand, users usually find the natural interaction methods more fun

and easier to understand. This means that developers have to take into account the type of game or application they are creating and what their target audience is when choosing the correct interaction method. People who like playing games might prefer the ones that can provide the best performance, while other users, like museum attendees might not care much about performance and would prefer methods that are more natural and easier to understand.

3.3 Virtual Body Ownership

As the focus are an experience in virtual reality, it is prudent to look into the essence of virtual body ownership. Professor Mel Slater, has been doing research within this subject. He made a definition of immersion and presence in VR in the paper: "A note on presence" Slater (2003). Here he defines presence as the following:

"Presence is the response to a given level of immersion (and it only really makes sense when there are two competing systems - one typically the real world, and the other the technology delivering a given immersive system)." Slater (2003)

He also says that you can immerse a person in a virtual reality environment by simulating the senses of the human body, with the use of different technology. Thereby making immersion objectively measurable, whereas presence, is the product of the immersion level you can achieve, and thereby a subjective measurement of the individual participant. Slater (2003)

Based on this, Slater has conducted several experiments measuring presence in VR, more specifically the illusion of virtual body ownership. He has conducted tests where he, with other scientists, try to understand when a person might feel this illusion of ownership of a virtual body.

Doing experiments in VR, he found that first person perspective was very important to a feeling of virtual body ownership. (Slater et al., 2010), (Maselli and Slater, 2013)

3.4 Aesthetics and Design for Game-Based Learning

This section is exploring parts of the book "Aesthetics and Design for Game-Based Learning". It is written by Michele D. Dickey, Professor at Miami university with

a PhD in Instructional Design and Technology. The book she has written focuses on aesthetics and their importance for GBL. She argues that since much game-based learning researchers relies upon science-based methodologies to document and analyse the data, and the researchers often forget the influence that aesthetics have on the human experience.

"Aesthetics are at the core of the arts and artistic media, yet too often science, as the prevailing mode of inquiry, misses the impact and influence of the aesthetics. Science-based methodologies provide a means for gathering and analyzing data, but they do not allow for the designer/ technologist to "get inside" the experience." (Dickey, 2015, p.5)

As Dickey points out, aesthetics in game-based learning have a big impact on gameplay (Dickey, 2015, p.5-6) and she has then categorized aesthetics in games in three categories:

- Aesthetics and Art Design
- Aesthetics and Interactive Design
- Games as Art

Aesthetics and Art Design Dickey describes it as being the format that evokes emotional responses in the player and then creates an impact on our behavior in the game.

Aesthetic and Interactive Design It is discussed that the interaction between the player and the game is also an aesthetic, as it also influences the relationships between the player and the game. As she quotes from Chris Crawford:

"Crawford stresses the importance of a game aesthetic that is process intensive vs. data intensive because it promotes more organic interaction." (Dickey, 2015, p.7)

Games as Art Dickey addresses this in the book by quoting many other game researchers who talk about that games incorporate aesthetics from other mediums such as literature, film and/or animation. From these discussions they all conclude that games are indeed art but in their own unique medium. (Dickey, 2015, p.7)

Educational Implications For educational purposes, Dickey points out that the player's positioning is important to consider when designing educational games. Considering the point of view of the player in the game is important as it might have a great impact on how the player perceive it. Dickey writes in her book:

"The result of this shift creates more engaging experiences for the player (Riddle, 2002). Similarly, with text-based games and the integration of detailed narrative in graphical games, the perspective (role the player is playing) and the POV (Point of

View) impact how the player is positioned as either internal or external to the game space. The use of first-person or even second-person POV includes the player in the game environment. Embodiment, as a function of the roles and the affordances as well as the constraints of the control mechanism, also impacts how a player is positioned.” (Dickey, 2015, p.51)

It is important to understand how aesthetics and the point of view affect the player experience and thereby the teaching of the subject. This also means that the immersion, which could come from such an experience, requires the suspension of disbelief. By this you might be able to create a connection between the educational purpose and the game, and thereby enhancing the learning outcome. (Dickey, 2015, p.51-52)

She also argues that an immersive experience in a first person perspective may not make the player reflect upon the topic, compared to if the player would see it from a third person perspective *”... that allow learners to become critical participants in the construction of knowledge.” (Dickey, 2015, p.53)*

Dickey has made a guideline for learner positioning in GBL:

”Perspective - 1. Determine the relationship between the learner and the game space.”

- Is it important that the learner be in the environment?
- How will the learner view the game-based environment (god’s-eye or external force, first-person or third-person)?

Narrative - 2. Determine the role of the learner.

- Is the learner a pre-scripted character, or will learners create their own character and role?
- How will this role be conveyed to the learner and reinforced?

Embodiment - 3. Consider the types of controls and viewpoint and the learning goals.

- What are the affordances of the avatar?
- What are the affordances of the controls?
- What do you want the learner to view and not view?

Immersion - 4. Determine the type of immersive experience that best meets the needs of the learning goals.

- Would the goals of learning best be supported by an environment that is emotionally immersive or reflective?

(Dickey, 2015, p.53)

Experience Design and Physical Spaces

Dickey also talks about that a focus on the experience as a whole is important to consider, as it also has an impact on how you learn. She uses the term of experience as: “often used in relation to creating processes, products and environments that have an emotional impact on user experiences” (Dickey, 2015, p. 107) Thus if your emotions are invoked you will maybe become immersed and thereby, your learning outcome will be greater. She says that many physical places also make use of experience design, e.g. Museums and Cathedrals, but she also mentions Virtual Reality and Virtual Worlds could also have some impact on learning. She says that the big physical places museums have give space to reflect upon what you see.(Dickey, 2015, p. 107)

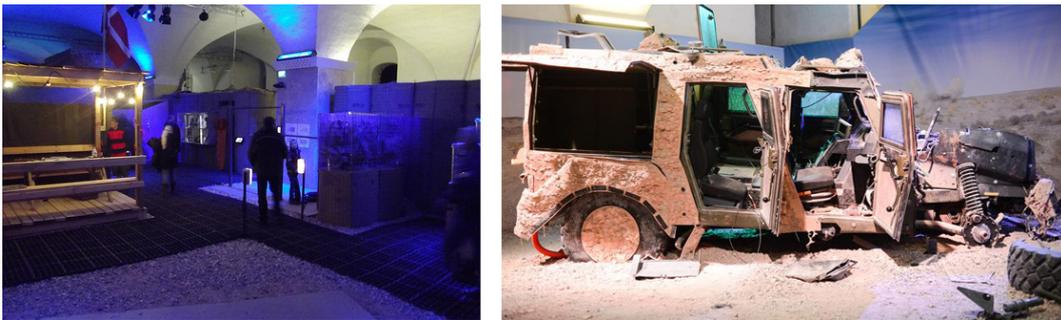


Figure 3.1: *Example from Tøjhus Museet "Den Fjerne Krig". Left - (farm8), Right - (NatMus.dk)*

She also argues that virtual reality also gives the possibility for the player to have a similar "big place" where they can reflect upon what they see. The player can also interact with the things in the virtual world, which may lead to a better understanding and learning of the content and context. (Dickey, 2015, p. 112)

Aesthetics and Games

Dickey sees games as art, and says that they also are type of drama. As she writes "...the aesthetics of game mechanics help inform the design of game-based learning by looking at the types of mechanics (core and secondary) and how they may foster different types of artistry of intellectual engagement. " (Dickey, 2015, p. 126)

Michele quotes Adams and Dormans who have made a list of five types of game mechanics (core mechanics) and explain that the list gives some good pointers on how to design interaction for game-based learning. (Dickey, 2015, p. 127 - 128)

- Physics
- Internal Economies
- Progressive
- Tactical
- Social

The most important ones for this project are: Physics, Progressive, and Social mechanics.

- Physics is how the game objects interact in the game space and how the player moves in the space.
- Progressive is how the player progresses in the game.
- Social is how the player interacts and/or collaborates with others in the game.

(Dickey, 2015, p. 127) **Educational Implications** For educational implementation of these mechanics Dickey refers to the table from Adams and Dormans which has the different mechanics ordered in what category they lay under constructivist learning. She says that the essential part of constructivist learning is that knowledge is constructed and that the one who would learn is not a passive user, but an active user that takes a part in the learning process. (Dickey, 2015, p. 128)

Core Mechanic	Constructivist Learning
Physics mechanics	Experiential
Internal economies mechanics	Resources
Progression mechanics	Scaffolding
Tactical mechanics	Inscription
Social mechanics	Discourse tools

Adapted from Adams and Dormans, 2012

Figure 3.2: *Example of core mechanics and constructive learning.* (Dickey, 2015, p. 129)

Connoisseurship and Game-based Learning

When it comes to determining if an educational game actually teaches the learner or player about the subjects, Professor Dickey argues that it requires connoisseurship. A connoisseur is a person who has years of experience and is competent enough to pass critical judgement. According to Michele Dickey it requires years of experience to determine if a learner or a player are actually learning from the created application. She describes a connoisseur of Game-Based Learning as a person who has been working with teaching for several years and knows multiple different teaching methods. They also need a great knowledge within media and its different aesthetical expressions and needs to have a knowledge of how game design works. This is required to determine if an educational game is having the outcome of teaching about the subject it covers. (Dickey, 2015, p. 141 - 142)

3.5 Theory of Fun for Game Design

3.5.1 Functionality of the Brain - Learning from patterns

Second review is for the book "Theory of Fun for Game Design" by Raph Koster(Koster, 2013). In this book Koster looks at games as a learning tool. He has been looking into studies about cognitive science. He states that the brain works as a pattern recognition machine. As humans, we always look for patterns. He also writes: "Seeing patterns in how kids learn is evidence of how pattern driven our brains are." (Koster, 2013, p. 16) He comes with an example of how you can find a face almost anywhere. A notable example is one that made many people think that there was life on mars. See Figure 3.3.

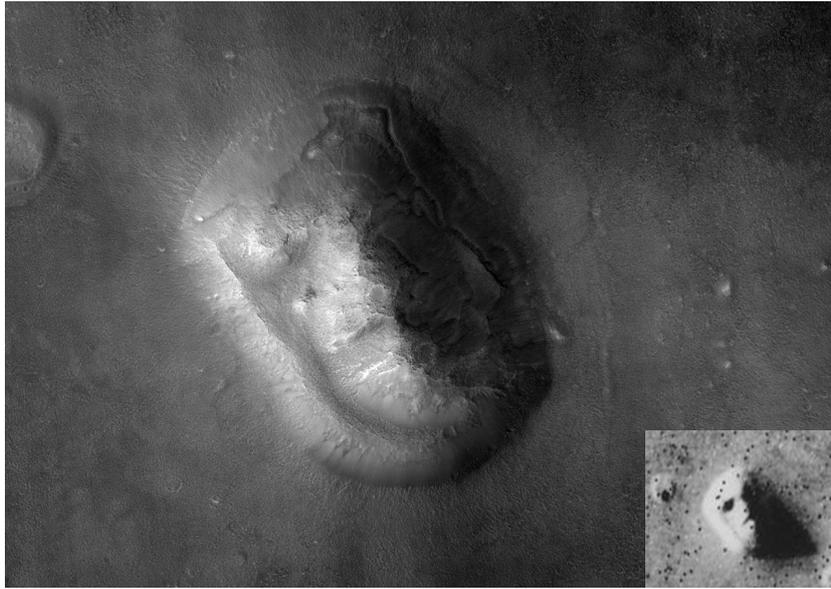


Figure 3.3: *Example of a pattern in completely random rock formations on the martian surface* ESA (2006). Picture from Wikipedia.

This is referred to as “Chunking” and we do it all the time. Other things we do as humans a lot are routines. Routines become “chunked” into your brain and become something you do regularly without thinking about it. (Koster, 2013, p. 18 - 20) In fact, most normal activities we see and do are also ”chunked” patterns. As Raph Koster writes:

“We rarely look at the real world; we instead recognize something we have chunked and leave it at that. The world could easily be composed of cardboard stand-ins for real objects as far as our brains are concerned.” (Koster, 2013, p. 22)

When you actually begin to think about what you do as a routine, it becomes rather hard to do it, e.g. morning routines. The opposite of a pattern is noise, but, according to Koster, noise is just a pattern we have not yet ”chunked”. (Koster, 2013, p. 22)

From this, the word “Grok” appears and it means that you have learned something so well that you intuitively know how to do it. E.g. playing guitar or riding a bike. You do not have to think about how to move your fingers or move your legs, you just do it, as if your muscle had memory. What is actually happening is that while you are practicing something, you store the “Grokking” in the brain in a sort of library. When you are sleeping your brain begins to process this information and makes sure that your practice is stored in your memory. Ultimately you practice

enough that it feels like it has become a routine (Koster, 2013, pp. 28 - 30)

3.5.2 Games as learning tool?

Games also have patterns that can be "grokked". One difference between reality and games is that the stakes are much lower in games (Koster, 2013, p.- 34). From dodging enemies to learning the controls, it is all a pattern that we practice over time and in the end, it sometimes becomes a routine of how we play games. We know where the buttons are on the controller, keyboard or mouse, we know how the enemies behave, and we know how the game mechanics work. We have learned from the game how to solve the problems that the game has presented to us, but that can also become a problem as the player becomes bored. At that point, the player has mastered the practice. As an example, Koster mentions tic-tac-toe. A very simple game with simple mechanics that can become boring after several tries, because you do not learn any new pattern or use those patterns in a new way. (Koster, 2013, pp. 36 - 38) Your brain need something new to learn; "... *with games, learning is the drug.*" (Koster, 2013, p. 40).

Koster gives a definition of a good game as "... *one that teaches everything it has to offer before the player stops playing.*" (Koster, 2013, p. 46)

His opinion is that games teach aspects of reality through fun; how a person understands one self, understands actions of others and help them use their imagination.

"Fun is just another word for learning." (Koster, 2013, p. 46)

3.6 MDA: A Formal Approach to Game Design and Game Research

The paper by Hunicke et al. (2004) has made a framework that takes into account the vision of the game developer and the game user. The picture below defines how the two different groups approaches a game



Figure 3.4: *How a game is seen, objectively.*(Hunicke et al., 2004)

In the paper they talk about how sometimes game designers think in mechanics when creating games. This is an issue that often comes up for the player - they may not understand what the purpose of the mechanics are. They have showcased that what the developer has in mind when they create a game is often like this:

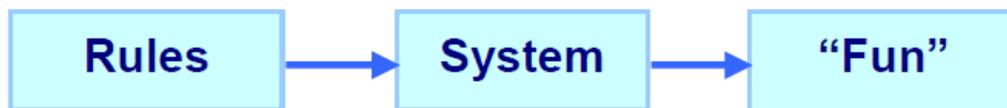


Figure 3.5: *Game development progression.* (Hunicke et al., 2004)

The problem is that the player does not always understand the system in the same way. Hunicke et al. (2004) came up with the framework they named "MDA" which stands for "Mechanics, Dynamics and Aesthetics", see Figure 3.6.



Figure 3.6: *MDA*(Hunicke et al., 2004)

- **Mechanics** are the components of the game, how you should play it.
- **Dynamics** is the way the mechanic reacts to player input etc.
- **Aesthetics** are how the player perceives the dynamics. (Hunicke et al., 2004).

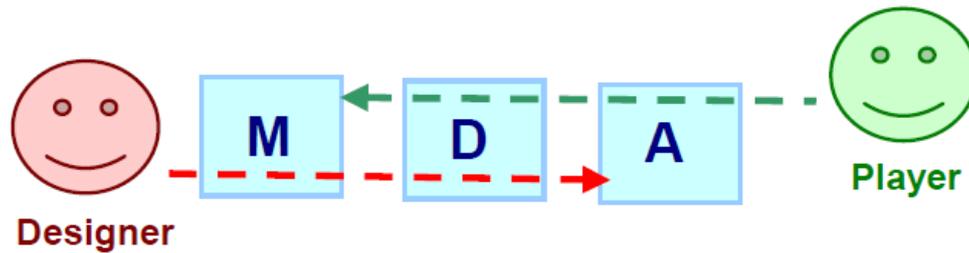


Figure 3.7: *The Different Approaches to a Game* (Hunicke et al., 2004)

It is important for the game designer to know these points because else they might fail to make their game fun for the player. This would be if the game designer thinks mechanics is equal to aesthetics, which is not true. The dynamic needs to be heavily considered to bridge the gap between mechanics and aesthetics. Therefore, as Figure 3.7 shows, it is important to note how to approach the game from both sides when developing. (Hunicke et al., 2004)

3.7 An Architectural Approach to Level Design

In this book, there is a chapter about teaching through visual communication (Totten, 2014, chapter 4). It has a section titled "Teaching Theories for Game Levels" which contains three different methods to teach a player the mechanics of the game. These methods are:

- Operant Conditioning
- The Montessori method
- Constructivism

(Totten, 2014, p. 162)

3.7.1 Operant Conditioning

The operant conditioning is a method that involves changes in the voluntary actions of the player, either via positive or negative reinforcement or punishment (Totten, 2014, p. 163). An example of this was a test done on rats that would pull a lever and if it was within the correct time, it would gain a reward in the form of some food. If it was the wrong time, it would receive a punishment in the form of an electrical shock (Totten, 2014, p. 163). This is also a good method to test basic

game mechanics. Totten talks about the game “Super Meat Boy” where you are first presented with a gap that you need to jump across, but you realize that you would need enough speed in order to jump far enough. The positive reinforcement would be that if you do it correctly you will get to the other side. The negative reinforcement is that if you do not have enough speed, the player dies and you have to try again. You would then repeat this process until you learn the mechanic. (Totten, 2014, p. 164)

3.7.2 Montessori Method

This method “emphasizes the senses as a medium for absorbing information that is then interpreted by the intellect into solutions to practical problems.” (Totten, 2014, p. 165). This indicates that the game level should be seen as “prepared environments of interactive objects for player to utilize” (Totten, 2014, p. 165). Because the Montessori method is based on that, you would try to solve a problem with objects or mechanics in games. The player should only learn each skill individually and not combined, followed by introducing the player to a mix of two or more of these skills and then continuing on (Totten, 2014, p. 166). Figure 3.8 shows how the designers behind the game “SWARM!” first separately introduced two basic puzzles and then combined them.

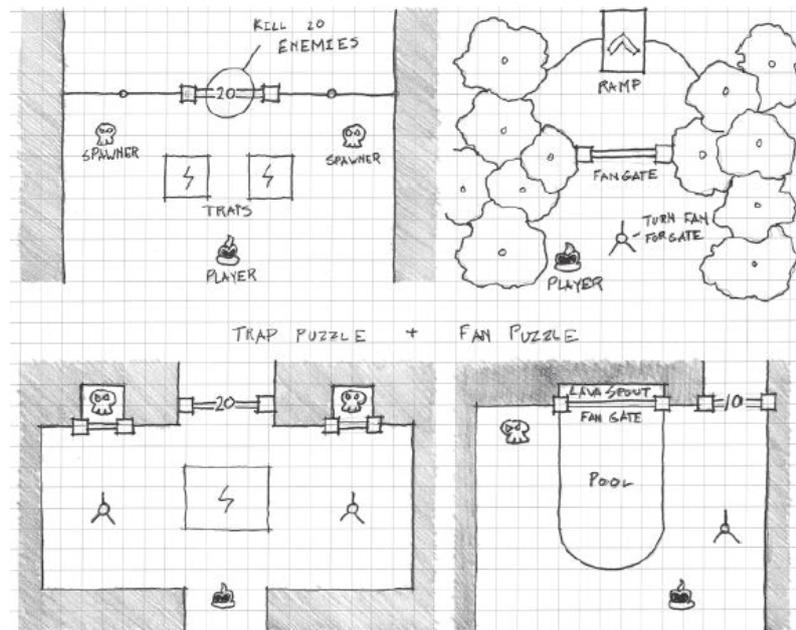


Figure 3.8: *Example of the Montessori Method in the game "SWARM!"* (Totten, 2014, p. 166)

3.7.3 Constructivism

Constructivist learning is a method used in many educations.

"In many studio classes, students are guided through a design problem by teachers who oversee but do not directly intervene in a student's design actions. This combination of freedom and feedback make constructivist methods a better individual descriptor of how players learn in games than either operant conditioning or the Montessori method alone." (Totten, 2014, p, 167)

Constructivist teaching uses both the Montessori and operant conditioning methods for problem solving. The main point is that the designer would only create interactive environments and challenges that the players could then freely experiment in in order to solve the problem. If the player completes the challenges they gets rewarded for their actions. Punishments and setbacks are also important, however the should not be too severe, so they can come go back and retry the challenge. This provides a very practical approach on how to learn new things and new mechanics. It makes it possible to say there is no right or wrong approach on how to solve a puzzle in the game. Figure 3.9 illustrates this. (Totten, 2014, pp.

167 - 168)

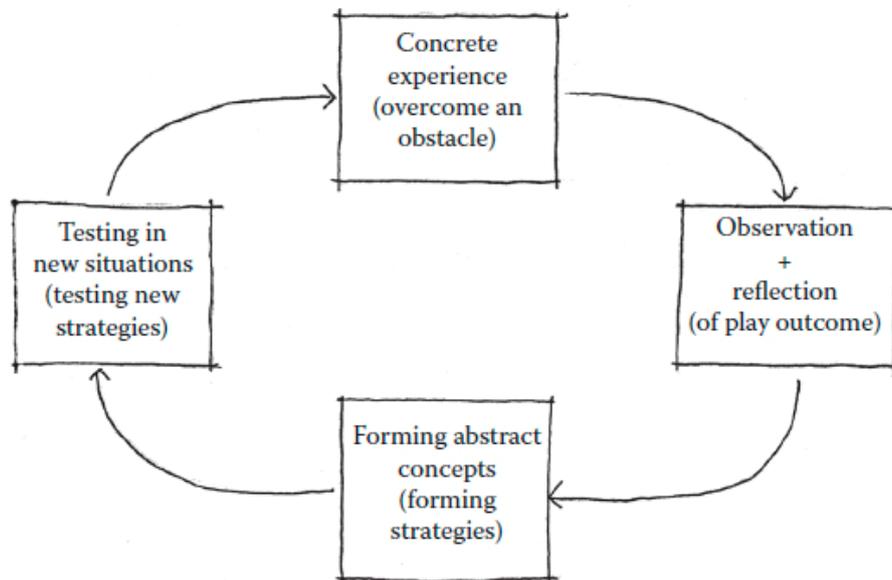


Figure 3.9: *Model of learning by Kolb and Fry.*(Totten, 2014, p. 168)

3.8 Discussion and Conclusion

This chapter has covered different articles and books from various topics related to this project. (McMahan et al., 2010) and (Nabiyouni et al., 2015) attempted to compare different interaction methods, respectively focusing on two and three different methods. The common conclusion was that the traditional interaction methods were most efficient and the natural interaction methods were the most fun, but less efficient. The experiment from Nabiyouni et al. (2015) also contained a semi-natural interaction method, which is a concept that might be relevant to this project. Based on the work of Maselli and Slater (2013) and Slater et al. (2010) using an HMD instead of a regular monitor gives a higher sense of presence (Slater, 2003). When combining this with the interaction methods, discussed and chosen in the investigation chapter 2, the motion controller (HTC Vive) can be defined as a semi-natural interaction method, as it serves as an extension of the player's body in the virtual environment. The Leap Motion would then be a natural interaction method, as it directly represents the hands of the user. This ties into the work by Hunicke et al. (2004). The in-game representation of the different

controls would be the dynamic bridge between mechanics and aesthetics. The importance of aesthetics should also apply to the rest of the project, as theorized by Dickey (2015) as it might enhance the player immersion and the potential learning outcome. If this is true, the way Koster (2013) defines games as learning tools might mean that the amount of fun the player has might also increase if they are tasked with learning a new pattern of a game mechanic. Such as, if they were thrown into an experience and allowed to explore the mechanics in an attempt to solve the given challenge, which is defined as constructivist teaching by Totten (2014).

Chapter 4

Final Problem Statement

For reader's convenience the initial problem statement reads:

How do different interaction methods perform in Virtual Reality and what would be the most ideal choice out of either natural or traditional control methods for a VR museum installation?

In order to refine the problem statement, the conclusions of the previous chapters will be used to delimitate into the final problem statement.

4.1 Delimitation

After looking into the state of some current Virtual Reality technology, the Leap Motion sensor and the HTC Vive motion controllers were chosen as the methods that will be implemented and compared in the final prototype, as they are able to both function in similar ways in the same environment. Based on the literature review, these two methods can be respectively classified as natural and semi-natural.

Based on the literature about game-based learning and a review of some of currently available VR museum applications, it was decided that the prototype will rely heavily on player interaction in order to engage the player. Most other VR museum applications only provide a different way of looking at things you would normally be looking at in a museum and are not capable of fully engaging a player, because the player only remains an outside observer in the virtual environment. The learning aspect will also aid in engaging the player, as they will maybe become interested in learning things.

From the museum considerations in chapter 2 it was decided that the prototype will be a group experience that will allow the person wearing the VR headset and the other people around them to actively take part in the same experience. This also lead to the conclusion that the user's enjoyment needs to take priority over how well they perform when playing the prototype. This means that making the experience as accessible as possible to as big of an audience as possible will be a big focus. The choice between the different control methods will be decided based on the users' collective subjective preference, rather than trying to reach an objective conclusion based on other factors. Finally, the practicality of each control method in a museum environment will be taken into account.

To encapsulate all the mentioned factors, the Final Problem Statement was formed as follows:

In a learning based, cooperative virtual reality game, how does the semi-natural control method of the HTC Vive controllers compare to the natural control method of the Leap Motion sensor in regards to user preference, usability and practicality?

Chapter 5

Methodology

5.1 Introduction

This chapter will go over the methods that will be used to gather data and perform the experiment.

5.2 Research Methods

According to the final problem statement, the experiment should investigate the users' preference between two different interaction methods as well as the amount of difficulties they had. These two points fall within the subject of User Experience, or UX. The final point from the FPS, practicality, would need observations of the prototype in use as well as interviews with industry people with experience in installation design and maintenance.

5.2.1 Testing User Experience

A tried and true way of getting data on a users experience with a product is to use questionnaires (Schulze and Krömker, 2010)(Lazar et al., 2010). This, along with interviews with a small number of the users can give an insight into how people think about and interact with the product. For test participants to give an informed view of their preferences regarding the interaction methods it is necessary for them to try both methods. In this case a within-group procedure is necessary.

5.2.2 Observation

The FPS also mentions practicality as a success criteria for the project. Using observation it is possible to gather more data on how people interact with the product and how the product performs in general. From this it might be possible to make conclusions about the practical aspects of the prototype as well as the area it should be set up in (Lazar et al., 2010).

5.2.3 Analysis

For data analysis on the Likert-type questions from the questionnaire, Boone and Boone (2012) says that evaluation should use the median to indicate central tendency. For variability and correlation you should use frequency and Kendall tau B respectively. Testing for significant difference between data should be done with a Wilcoxon rank-sum test as it is not possible to make the assumption that the data will be normally distributed. For the rank-sum test the P-value will be set to 0.05.

5.2.4 Design of Product

Since the product is such a large part of the experiment setup it will need to be thoroughly tested and relatively bug free. Using an iterative design process will not only allow for many tests of the stability and usability of the prototype but can also help improve the design of the experiment itself (Nielsen, 1993).

Chapter 6

Iterative Design and Testing Process

6.1 Requirements for Experiment and Prototype

Based upon the Delimitation and Methodology, there are certain requirements that must be followed in order to achieve an answer to the problem statement. A number of functional and non-functional requirements for the prototype and for the test will be set. This section will cover the different requirements, from a hardware and software perspective, requirements for the prototype design itself and requirements for the experimental setup.

Functional Requirements

1. **Different interaction methods.** Since the main experiment is about testing user preference between two different interaction methods, the same prototype needs to be able to function in a similar way with both the HTC Vive motion controllers and the Leap Motion sensor. This also means designing for each method to make use of its strengths to ensure the comparison is fair.
2. **Sustain a high level of authenticity.** Because this is a museum installation, it needs to fit into the museum environment. This means that all the objects in the scene and how they function need to be historically accurate and that will require doing research into those aspects. This also means using appropriate sound effects and environmental details to create a believable and authentic environment.

3. **World War 1 Theme** As this particular installation is going to be made for Mosede Fort (Greve Museum), it must fit into the specific museum theme, which is Denmark during World War 1.
4. **Provide an enjoyable and accessible museum experience.** Since the prototype is intended to be presented in a museum, it has to be both accessible and enjoyable to a wide audience. If a museum installation is not enjoyable or too complicated, visitors will not be interested in interacting with it.
5. **Testing in a museum environment** As the experiment is meant to chose the right interaction method for a museum installation, the testing environment should mirror that in order to get the best results.

Non Functional Requirements

1. **Game Engine that can properly utilize the hardware** For this prototype, it was important to chose the correct game engine to use that would be able to accommodate all the hardware that is being used - the room-scale VR setup of the HTC Vive, its motion controls and the Leap Motion sensor. The two main possibilities for this are Unity 5 and Unreal Engine 4, as they both have existing plugins that allow the use of the three mentioned pieces of hardware.
2. **90 Frames Per Second.** The VR application needs to run at a minimum of 90 frames per second to minimize the amount of motion sickness a user will get while wearing the VR headset (UE4). In order to achieve this, the project will have to be optimized by making sure there are no needlessly detailed objects or inefficient code that could negatively affect the performance.
3. **Compliment the teaching of primary school mathematics.** The prototype is meant to teach users real world application of primary school mathematics. This will be achieved by having the player that is currently using the VR headset require information that can only be gathered by having other users outside of the application do mathematical calculations in order to achieve the goal of the game - hitting the chosen target with the cannon.
4. **Intuitive controls.** Because this application is meant to be used in a museum, it will most likely be used by a large variety of people, which means the controls need to be very accessible to make sure that any museum visitor could get the most out of the VR experience. The natural control methods will help make the controls easy to understand, even to users that have not

tried VR before.

5. **High level of usability.** To create the most enjoyable overall experience, the setup of the installation also needs to be clear and understandable and not just the application itself. This means that the players outside of VR that are doing the calculations should also be able to achieve their task without interruptions or obstacles. This would mean providing them with easy to read maps, giving them the necessary formulas and easing them into the experience to make sure they do not get intimidated by having to do a lot of complicated math right away. Finally, this means creating an easy to read and understand interface inside the application so the VR player can get all the required information fast and easy.

6.2 Danish Learning Festival

6.2.1 Test overview

The test was carried out on the 15th and 16th of March 2016 in the Bella Center convention center in Copenhagen. The testing area was an open booth that anyone interested could come to and try the prototype themselves or watch other people trying it. The version of the prototype used in this test only had the motion controller input implemented and it did not yet contain the natural movement interaction. All interaction was still done by having the user move the controller over an interaction point and pulling the trigger to play an animation. In this version, the only way to change the target that the user would be firing at was to reset the entire scene with a button, which introduced some bugs and that lead to often having to shut down the prototype and start it again. This version also did not yet have any diegetic feedback, as all the information to the player was presented via floating text locked to the player's view. Since this was an early test, the experiment questionnaire was not yet created, so it served as a way to test the basic mechanics of the prototype. The participants only played the prototype as much as they wanted and then gave verbal feedback if they wanted. Test participants consisted of both children and adults that were attending the convention.



Figure 6.1: *Test at the Danish Learning Festival.*

Observations

As this test was the first live testing of the installation with participants from the public a lot of observations were made, particularly with regards to usability. It was also pertinent to look at how people interact with the virtual environment to further improve on the experience afterwards. Lastly, this test was also a way to find bugs in the software so they could be fixed.

Visibility and affordability of the cannons handles was a big problem for the users. People would often be confused and have to ask the conductors for help and instructions on what to do next. The handles and other parts of the cannon they had to interact with were difficult to pick out from the rest and the users ended up trying to interact with non-interactable parts. Another, unanticipated, problem was the instability of the controllers. During the development period the controllers themselves had always been very stable but in the intense WiFi noise of the convention hall they kept losing their connection with the PC, causing them to be very unreliable. This was also a major problem for the users.

Besides the technical side of the installation, the users also needed better explanation of how to do the math and the general procedure for working together. They would not communicate with the person in the virtual environment and be generally confused when presented with the map and measuring tools. The VR users would also have trouble using the controllers. It seemed a lot of people, both children and adults, had never interacted with similar controllers before and would even sometimes hold the controllers the wrong way up, using their thumbs on the trigger.

During the experience many people showed similar patterns in their interaction. Almost all participants tried to throw things in the virtual environment. The prototype was not equipped for this and they were usually disappointed. Another part that confused people was the lack of natural controls on the wheels that steer the cannon. People would try to turn the wheels but in reality they just had to press the right or left side of the wheel to turn it in the corresponding direction. It was difficult for people to get used to this and it was also difficult to explain to the participant. Even then, kids kept coming back to try the installation. Every time they returned they had brought more of their friends and classmates with them.

During the two days, people mostly came by in groups. Groups of adults or groups of kids but only very few mixed groups. When asked about their experience people gave mostly positive feedback even though they might have met massive technical issues due to the early stage of the prototype. Users who had tried VR before compared the installation positively to their earlier experiences.

Finally, one observation that permeated the two days was that people do not want to or are very reluctant to do math. If they agreed to help their friend in VR by doing the math portion of the experience they would often give up easily or be utterly confused about how to complete the task.

6.2.2 Conclusion

From the observations it was obvious that the prototype needed a usability overhaul and several bugs were also found in the software that had to be fixed. Because of the users general confusion at the math portion of the experience, a way to instruct the users in how to use the maps and do the math was also deemed necessary. Overall the test showed that the prototype, though flawed at this point, already made an impression on people and especially children.

6.3 Singularity University Event

6.3.1 Test overview

This test was carried out on the 29th of March in the Dare2mansion creative center in Copenhagen. The version of the prototype used was the same as used in the Danish Learning Festival test.

6.3.2 Observations

At the Singularity University event people came to the installation in their breaks and while they all seemed very interested, they were in a hurry. As many people as was possible got to try the prototype but there were many that had to leave without trying it out. Because of the rushed nature of the circumstance, no effort was made to get participants to use the map to calculate.

Even though there were no children present, the observations match the ones made at the learning festival. People were impressed with the installation even though it lacked proper intuitive controls and contained experience breaking bugs.

6.3.3 Conclusion

As this test was held very soon after the last test it was not possible to produce a new version of the prototype. Because of this the observations made did not give any new insights.

6.4 Nordic Game Jam

6.4.1 Test overview

This test was carried out on the 9th of April at Aalborg University Copenhagen campus while the Nordic Game Jam was being held there. The shown build had both interaction methods - the HTC Vive motion controllers and the Leap Motion hands. It also had the more natural controls of being able to grab and drag the levers and valves of the cannon with either control method. Moreover, it had some of the miscellaneous object interactions implemented that users could play around with, like the binoculars and the smoking pipe. This version had some of the diegetic feedback implemented via the dials near the valves that displayed the angle and rotation values of the cannon, but the target location was still displayed as floating text locked to the user's vision. This test still served as more of a pilot test of the mechanics and functionality of the prototype and thus participants were not asked any specific questions and just gave any verbal feedback if they wanted to. Test participants consisted of people participating in the game jam itself, game jam staff, as well as some people from the games industry that had given talks or presentations the day before.

6.4.2 Observations

Most of the people who tried the prototype did so using the Leap Motion hand method. Most of the participants were either game developers or just people who were already interested in games and therefore more familiar with more traditional control methods, so they found the Leap Motion method a lot more novel. Despite the fact that the Leap Motion sensor hand tracking is not very precise and caused a fair amount of difficulties when people were trying to interact with the cannon, most people still wanted to keep using it, even when offered to change to using the more precise motion controllers. The reception to the introduction of the natural interaction was very positive and people found it a lot easier to manipulate the cannon. The introduction of the binocular and the smoking pipe also had a very positive reaction. People generally found the experience pretty enjoyable and interesting. When asked about what they thought of the learning aspects of the project they usually responded saying that it sounded interesting and that they like the idea of requiring communication between the player in VR and the other participants.

6.4.3 Conclusion

Both the introduction of the Leap Motion hands and the natural interaction was a massive step forward in terms of usability and user experience. Giving the more environmental interaction helped them get more engaged and helped add variety. This could potentially allow the users to get a better understanding of the different controls and give them a better understanding of their preference. The desire of the participants to keep using the Leap Motion no matter what could mean that the pure novelty effect of the Leap Motion might help overcome its technical limitations.

6.5 Mosede Fort and AAU Demo Day

6.5.1 Test overview

Mosede Fort

This test was carried out on the 26th of April at the Mosede Fort museum. The version of the prototype used was almost the final version and it had almost all of the functionality of the final prototype. The floating text was completely phased

out at this point, as the current target location was now displayed on a physical blackboard in the VR environment that would also display whether the user has hit or missed the cannon shots. This version also introduced a built-in way to reset the prototype scene inside the VR environment via a lever next to the blackboard that the user could pull. This was the first test where the experiment questionnaires were actually used. Before the test, participants were asked to sign a letter of consent that gave us permission to use data gained from their questionnaire answers. Participants were asked to try both interaction methods, switching after performing the required tasks with one and then the other. Which method they used first changed from one participant to the next. After using both methods, they were asked to fill in a questionnaire. Addressing the problem of providing instructions to the players, this version saw the introduction of the tutorial booklet. This first version had all the steps laid out in text and had the specific tasks that of each role separated into their own paragraphs that were numbered. It also had images displaying the actions the user has to perform to use the cannon and how the user should be using the rulers with the map. Test participants consisted of a group of high-school students and a group of museum employees.



Figure 6.2: *Test setup at Mosede Fort.*

AAU Demo Day

This test was carried out on the 27th of April at Aalborg University Copenhagen campus. The version used was the same as in the Mosede Fort test. Test procedure remained mostly the same as the previous test. Test participants were mostly Medialogy students and a few Medialogy teachers. To test the design of the experiment we tried to have some participant only try one of the interaction methods. This was to see what impact this would have on the results gathered. After this

test it was deemed best to have participants try both methods since they needed to make an informed decision on the matter.



Figure 6.3: *Test at AAU Demo Day.*

6.5.2 Observations

The high school students at Mosede Fort were in a hurry and they seemed very disinterested in doing any kind of math. The ones that had time to try the experience liked it though. After the high school students had left the museum, a group of employees from the fort came to try. From a professional point of view they seemed impressed and they commented that this experience is something they would like to have as part of their exhibits.

The students that tried the prototype at the Demo Day were very interested in the cooperation part and they liked working together. However, they were still not too keen on doing math.

The biggest problem that was found during these two tests was the existence of a bug that made it impossible to hit the targets. This was because all the target locations were accidentally placed below the ground, just out of reach of the margin of error.¹

After these tests, we found that the tutorial booklet helped the users understanding of what they're supposed to do. However, some people did not want to read the entire booklet and would sometimes only look at the first page and then not pay any more attention to it.

¹We would like to apologize to our supervisor, Henrik Schønau Fog, for inadvertently letting him believe that he was missing the target.

6.5.3 Conclusion

The new additions to the prototype seemed to work well and the tutorial booklet was a big help to some of the participants. Through this iterative process the prototype and experimental design has been refined.

Chapter 7

Experimental Design

7.1 Introduction

This chapter will go over all the design of the final version of the prototype and how it was developed, along with the final methods and procedure used for the final experiment.

7.2 Design of the Experiment

This section will go through the type of experiment that will be conducted and will define the variables and hypotheses. It will also explain the design of the experiment based on the methodology chapter.

7.2.1 Design of Study

To figure out what kind of study is needed for this experiment, the number of variables and conditions can be determined from the FPS: *In a learning based, cooperative virtual reality game, how does the semi-natural control method of the HTC Vive controllers compare to the natural control method of the Leap Motion sensor in regards to user preference, usability and practicality?*

From this it can be determined that this is a true experiment, based upon the fact that the participants are going to be randomly assigned to the two conditions of the interaction methods. As this experiment focuses on the

preferred interaction method for a particular installation, this means there is a single independent variable. This makes this a basic study, with the two conditions being the HTC Vive Controller and the Leap motion. A within group design was chosen because it was required to see the preference of each participant. (Lazar et al., 2010, pp. 42 - 45)

7.2.2 Hypothesis

Based on the design of study the **Independent Variable (IV)** can be defined as:

- **Interaction Methods**
 - **HTC Vive Controller**
 - **Leap Motion**

The **Dependent variables** are defined as:

- **Difficulty Experience**
- **User Experience**

Based upon the defined variables, the hypotheses can be stated as followed:

Difficulty Experience Hypothesis

- **H0:** *There is no difference in difficulty experience between the HTC Vive Controller and the Leap motion*
- **H1:** *There is a difference in difficulty experience between the HTC Vive Controller and the Leap motion*

User Experience Hypothesis

- **H0:** *There is no difference in user experience between the HTC Vive Controller and the Leap motion*
- **H1:** *There is a difference in user experience between the HTC Vive Controller and the Leap motion*

7.2.3 Test Setup

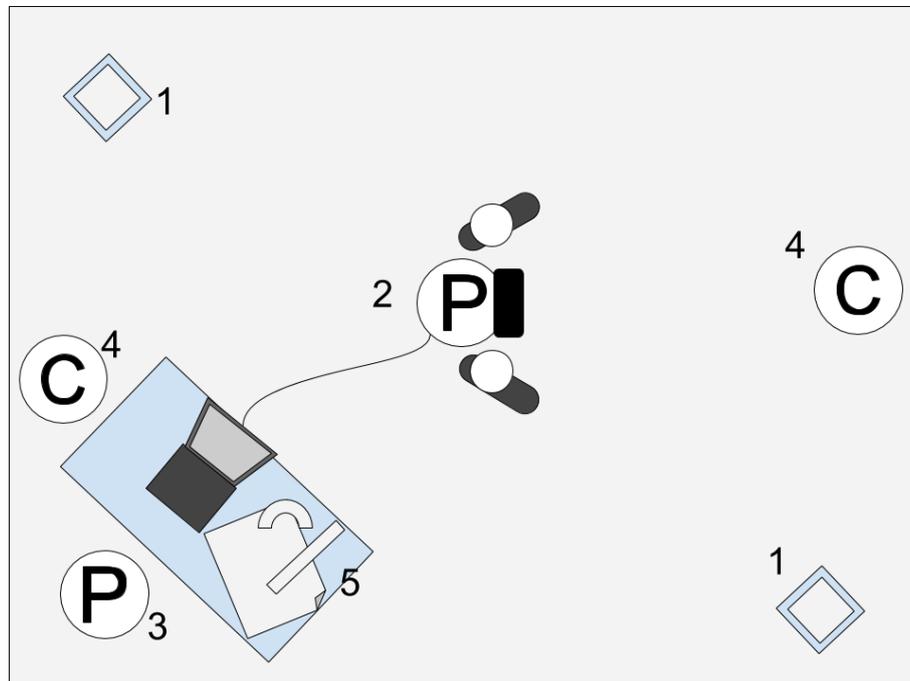


Figure 7.1: Overview of the test setup: 1. The HTC Vive "Lighthouse" sensors. 2. Test participant using the HMD holding the Vive motion controllers. 3. Test participant assisting with the map calculations. 4. Test conductors observing and able to assist if the need arises.

Figure 7.1 displays the basic setup of the hardware and the placement of the participants and the conductors.

7.2.4 Sampling

For sampling test participants for the experiment, convenience sampling was chosen, as it provides a fast and reliable testing for the product.

7.2.5 Test Procedure

In order to make sure that there is going to be an equal amount of participants trying both interaction methods first the participants will be assigned in the following order:

	Participant 1	Participant 2	Etc.
Condition 1	HTC Vive	Leap Motion	HTC Vive
Condition 2	Leap Motion	HTC Vive	Leap Motion

For the testing of the experiment, the test procedure will be the following:

1. Test conductors introduce the participant(s) to the consent form.
2. When a participant has signed the consent form, the test conductors introduce the participant(s) to the tutorial booklet.
3. Based upon the assigned interaction method, the test conductors, give a short basic introduction on how to use the device.
4. The test conductors ask the participant with the HMD to interact with the objects that are placed in the table while the other participant begins calculating.
5. The participant(s) play with the installation until they have hit the target and unloaded the cannon.
6. The interaction method is switched and item 4 and 5 are repeated.
7. After the first participant has hit the target twice they switch places with the other participant.
8. Item 3 to 6 are repeated for the other participant.
9. Participant(s) are asked to fill out the questionnaires.
10. (Optional) If a participant has the time they are asked if they would agree to a short interview.

7.2.6 Questionnaire

The questionnaire consists of three parts; Demographics, Experimental questions and Follow-up questions. The experimental questions are going to gather data relevant for the experimental hypotheses while the follow-up questions are gathering information relevant for later discussion. The demographic part is going to be used for correlation. For gathering data for the hypothesis, Likert-type questions will let the user indicate how they feel about certain aspects. To avoid users choosing a neutral answer and make them take a stance the amount of steps in the Likert scale will be set to 6; then there will be no middle number. Since participants did

not necessarily have prior knowledge of the Leap Motion it was referenced as "My Hands" in the questionnaire to avoid confusion.

Demographics:

D1: Gender (Multiple choice)

D2: Age (Number)

D3: Education (Multiple choice)

D4: Favourite Subject (Check list)

Experiment:

E1: Which Methods did you try out first when playing the game? (Multiple choice)

E2: User Experience - Controller (Likert scale, Very Boring to Very Fun, 6 steps)

E3: User Experience - My Hands (Likert scale, Very Boring to Very Fun, 6 steps)

E4: Difficulty Experience - Controllers (Likert scale, Very Hard to Very Easy, 6 steps)

E5: Difficulty Experience - My Hands (Likert scale, Very Hard to Very Easy, 6 steps)

E6: Which of the two methods did you like the most? (Multiple choice)

E7: Based on your answer above, can you please explain why? (Short paragraph)

E8: Do you think the different approaches of playing the game was good enough? (Check list)

Follow-up:

F1: The overall experience (Likert scale, Very Boring to Very Fun, 6 steps)

F2: Something you would like to try again? (Binary)

F3: Something you would recommend for your friends and/or family? (Binary)

F4: Is this something you would have liked to have had at your primary school? (Binary)

F5: Did you at any point during the experience get frustrated with the controls of the game? (Binary)

F6: Based on your answer above, can you please explain why? (Short paragraph)

F7: If there was ONE thing you would like to add or change, what would it be? (Short paragraph)

F8: Write anything for feedback (Short paragraph)

7.3 Design of Prototype

The prototype is made up of a single scene centered around a World War I Danish howitzer cannon located in an artillery battery at Mosede Fort. The experience

involves one player using the VR headset and one or more players watching them through a monitor that displays an outside view of what the VR player is doing.



Figure 7.2: *In-game picture of the prototype.*

The VR player is able to interact with various elements of the scene via the different interaction methods. The VR player's main goal is to correctly load and fire the cannon. In order to do that, they have follow these steps:

1. **Pick up** one of the artillery shells lying on the floor
2. **Load** it into the cannon
3. **Close** the loading mechanism
4. **Pull** the trigger.

In order to fire the cannon again, the steps are as follows:

1. **Pull** the release lever
2. **Open** the mechanism again, which will release the old shell
3. **Repeat** above steps

The player would be instructed on how to do this by the other players who would be reading these instructions from a booklet given to them. There are also some other miscellaneous objects placed around the scene that the user can pick up and interact with, like a radio or some binoculars that they can use to get the hang of the basic controls and to pass the time while the other players are doing

calculations. The VR player has to aim the cannon by rotating the two valves located on the side of the cannon. They are given feedback on the elevation and rotation values of the cannon, controlled by the two valves, via two dials located near the valves. The VR player is told the randomly chosen location of their target that they would pass on to the other players, and whether the cannon shot hit or miss when it is fired via a blackboard located in the VR environment. The user is able to change the language of the text displayed on the blackboard between Danish and English by using a lever in the environment. The outside players would be doing measurements and calculations on a map given to them in order to get the correct cannon elevation and rotation values to relay to the VR player so they could properly aim the cannon, based on the location of the target that the VR player gives to them.



Figure 7.3: *The map and the measurement tools that the players would have to use.*

When the cannon is fired and either hits once or misses three times, the scene can be reset by the VR player by pulling a lever in the VR environment.

7.3.1 3D modeling

All 3D modeling was done in 3D Studio Max 2010. Since all objects in the scene had to be as historically accurate as possible, a large number of reference photos were used when modeling the objects that were either taken by us at the museum

or found online from various sources. There were not many references available of the specific cannon itself that was used at the fort in World War I, so certain details on the cannon were created by basing them on other similar cannons of that time period or by having to guess how it might have worked.

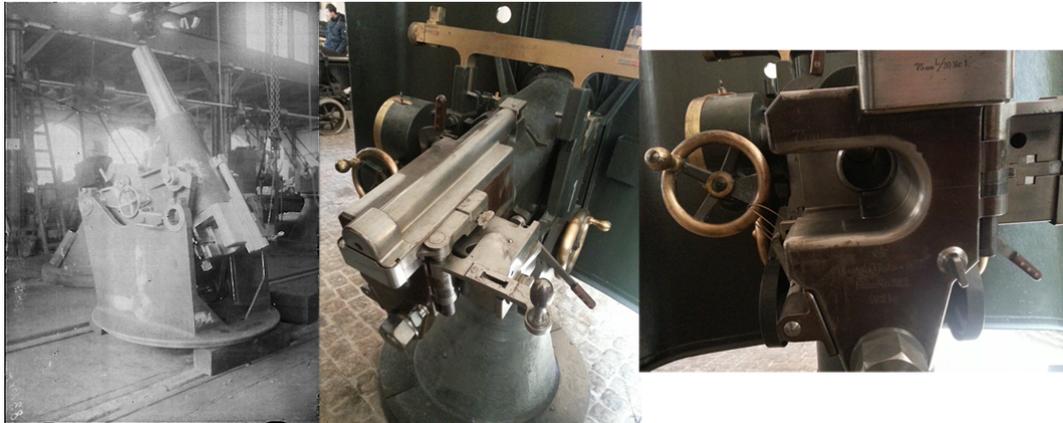


Figure 7.4: *An example of reference photos used to create the model of the cannon. The left photo is an original photo of the original cannon from World War I and the other photos are ones taken at the Tøjhus (Royal Danish Arsenal) museum of a cannon with a similar mechanism from the same time period.*

The result was a model that had many functional moving parts that could then be made interactible in Unity.

All the materials were made either in Adobe Photoshop CS5 out of various images found online or by using the procedural material creation tools in 3ds Max that were then rendered out into image files. Most of the finished materials had a color diffuse map, a bump or normal map and a specular map that were then combined in Unity to create the final material shaders.

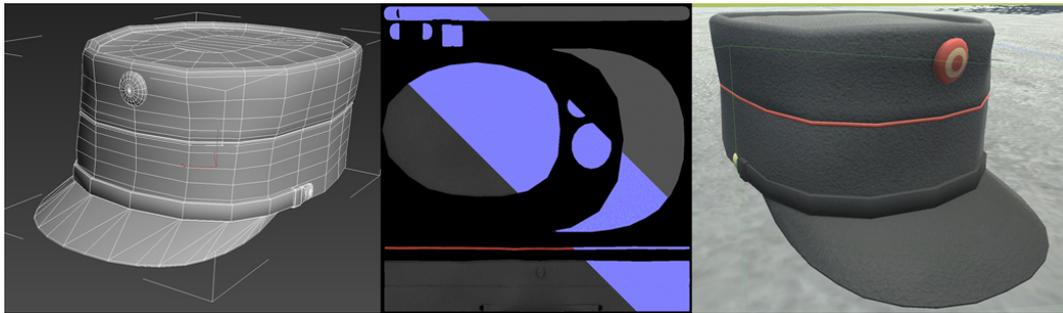


Figure 7.5: *An example of a model created in 3ds Max (left), three different texture maps that are combined into the final material (middle) and final model with final material shader in Unity (Right).*

7.3.2 Unity implementation

The application was made in Unity 5.3.4. The engine was chosen for its versatility and because the team has much experience working with it. Unity 5 also has 3rd party support for the HTC Vive from Valve corporation, and the Leap Motion has support from Leap Motion Inc. This kind of support makes the development process much faster as well as giving access to technical support.

To create a virtual environment that is authentic and realistic physics objects are required. This makes the world feel more real for the user while giving them the freedom to interact with the environment. Integrating Unity's built in physics engine with the Vive and Leap would have been a bigger challenge were it not for a 3rd party open source plug-in from Tomorrow Today Labs called NewtonVR¹. The package includes scripts to calculate and preserve momentum of objects, giving the user the ability to throw them. It also includes simple handles, levers and dials that work well for any natural or semi-natural interaction.

¹<https://github.com/TomorrowTodayLabs/NewtonVR>

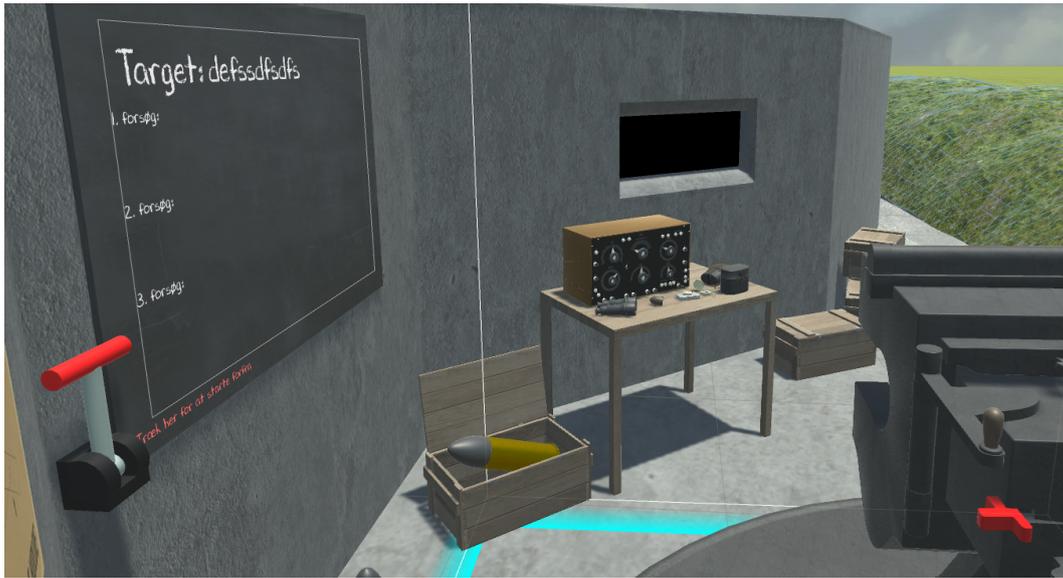


Figure 7.6: *The handle on the cannon, the dials on the radio and the lever on the wall are all fully interactable and use different variations on the NewtonVR Interactable script.*

NewtonVR was specifically made for the HTC Vive but with a few tweaks it can be made to also work with the Leap hand controllers.

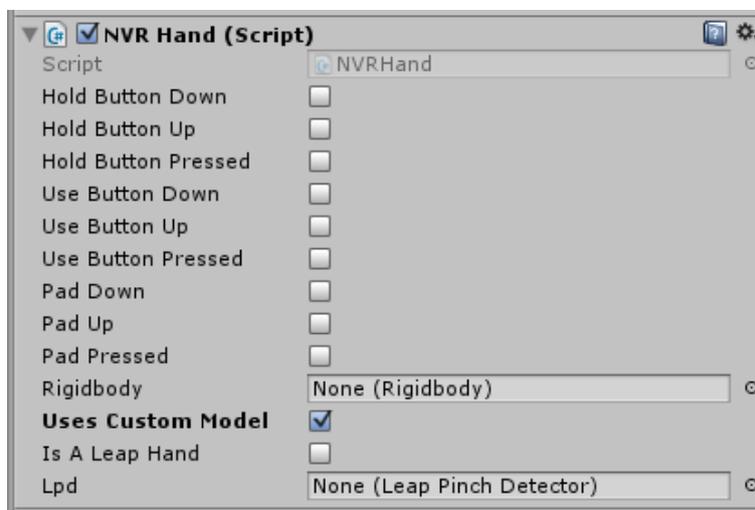


Figure 7.7: *The NewtonVR Hand script was changed so it can receive input data from the Leap Pinch Detector instead of the buttons on the controllers. It is possible to switch between the two behaviours with the public boolean "Is Leap Hand".*

However, the mechanic of shooting the cannon does not involve physics. Instead, to ensure that it will always hit the same spot given the same input, everything was done with math. Here is an example:

```
float RangeCalculation(float h, float v0, float a)
{

float vx0 = v0 * Mathf.Cos(Mathf.Deg2Rad * a);

float vyo = v0 * Mathf.Sin(Mathf.Deg2Rad * a);

float trise = vyo / 9.8f;

float maxh = (float)(h + vyo * trise - 0.5 * 9.8f * Mathf.Pow(trise,
    2));

float tfall = Mathf.Sqrt(2f * maxh / 9.8f);

float tflight = trise + tfall;

float range = vx0 * tflight;

return range;

}
```

This function takes the height of the cannon "h", the muzzle velocity of the shot "v0" and the angle "a", then returns the distance of the shot. Several functions like this are used to make sure the cannon is behaving in a realistic and mathematically correct manner.

User interface

The blackboard, seen in Figure 7.6, is used for giving feedback to the user. It will tell them if the target was hit, and if not, how many meters it was missed by. This is only visible to the person wearing the HMD. On the monitor, used by the other users, is a calculator that they can use to figure out the elevation angle the cannon needs. Their view can be seen in Figure 7.8.



Figure 7.8: *The monitor allows the users not wearing the headset a window into the virtual world. They also have access to a simple calculator to help them. Once they have measured and calculated the distance they input that number into the empty field. The output will be the angle needed to hit the target.*

Both the blackboard and the calculator use the Unity UI Canvas system. These are also connected to the Language Manager; a script that controls what language is being displayed to the users. With the push of a button or pull of a lever in the virtual world the language can change between English and Danish.

The cannon

Most of the articulated parts of the cannon are using the Unity Hinge Joints to make them behave in a realistic manner. In conjunction with the Newton VR script they move as you would expect them to. The barrel and stand of the cannon are rotated programmatically relative to the velocity of the turning valves. The only parts of the cannon that are animated are the barrel for the recoil and the loading and unloading of a shell into and from the cannon.

7.3.3 Paper Tutorial

As this kind of application is intended to be used in a museum, it needs to be possible to use it without having someone in person supervising and explaining the controls and mechanics to the players. For this purpose, a paper tutorial was created in the form of a short booklet that covers all the different steps that the players in different roles have to perform to successfully aim and fire the cannon. The booklet is in both Danish and English, with each of the language versions being on opposite ends of the booklet, so it could be flipped over to get the other language. Two iterations of this tutorial were created in an attempt to make it as easy to read and understand as possible. The final version of the booklet designed after the iterative design process. The main changes from the version mentioned in chapter 6 were a significant reduction of the amount of text in the booklet, the addition of some colored text and gray boxes to highlight the most important parts and also arrows at the bottom of each page to indicate that the user should flip to the next page to continue learning about the required tasks. Full tutorial booklet is included in the digital appendix.

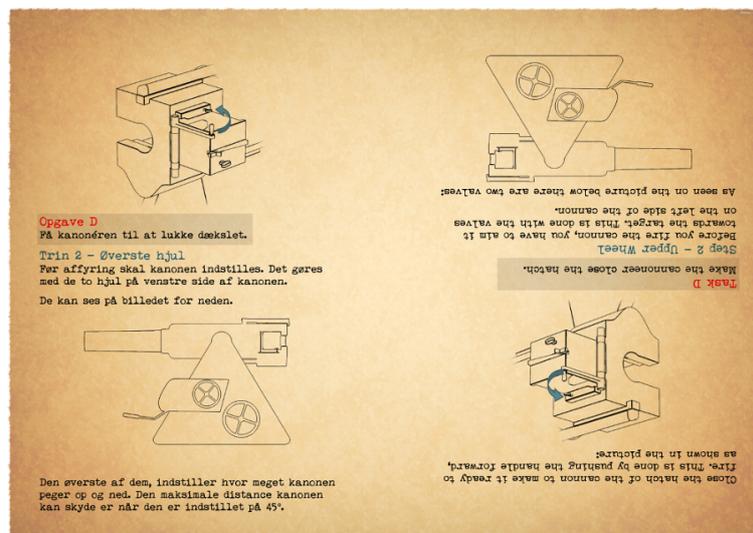


Figure 7.9: An example page of the final tutorial booklet.

7.4 Experimental Protocol

This section will sum up all the parts that need to be taken into account in order to reproduce this experiment.

7.4.1 Purpose of the Experiment

The purpose of this experiment is to test if there is a significant difference between the two interaction methods, HTC Vive controller and the Leap motion, in a World War 1 themed collaborative VR installation game, to serve as part of Mosede Fort.

Independent Variable	Dependent Variables
<ul style="list-style-type: none"> • Interaction method <ol style="list-style-type: none"> 1. HTC Vive Controller 2. Leap Motion 	<ol style="list-style-type: none"> 1. Difficulty Experience 2. User Experience
Difficulty Exp. Hypotheses	User Experience Hypothesis
<ul style="list-style-type: none"> • H0: <i>There is no difference in difficulty experience between the HTC Vive Controller and the Leap motion</i> • H1: <i>There is a difference in difficulty experience between the HTC Vive Controller and the Leap motion</i> 	<ul style="list-style-type: none"> • H0: <i>There is no difference in user experience between the HTC Vive Controller and the Leap motion</i> • H1: <i>There is a difference in user experience between the HTC Vive Controller and the Leap motion</i>

7.4.2 Materials and Equipment

The required equipment and materials for conducting the experiment are:

- 1x HTC Vive set
- 1x Leap Motion sensor attached to the front of the HMD
- 1x Computer capable of Running VR applications
- Monitor(s)
- Computer(s) for questionnaire
- Map(s)
- Ruler(s)

- Angle Ruler(s)

7.4.3 Setup and Procedure

For the setup of the equipment look at Figure 7.1. The experiment should be conducted on groups of people and have one of them start in VR, while having others be looking at the monitor and handling all the calculations and instructions. The person playing the prototype should try both interaction methods in differing order. When they have tried loading and firing the cannon with both methods, they participants should change roles. When all the people from the group have tried the prototype, they should then fill in the questionnaire about their experience.

7.4.4 Methodology

- Convenience Sampling
- Random assignment of starting condition
- Questionnaire
- Observation
- Interview

7.4.5 Data Analysis

For analysing the data the Wilcoxon Rank-sum test should be used for significant difference tests, as the medians that are going to be compared. To see if there is a correlation between the two Dependent variables, Kendall's Tau Correlation test is also going to be used, as it measures the medians.

Chapter 8

Final Experiment

8.1 Test setup and procedure

This test was spread over multiple locations - three tests in different areas at Aalborg University Copenhagen on the 4th, 5th and 6th of May and one test at University College Copenhagen on the 9th of May. The participants would come in groups and then chose which one of them would first use the VR headset. Others would then be seated near the computer monitor where they would have the instructional booklet, the map and all the measuring tools. The person in VR would try both interaction methods one after another in differing order and then the participants would switch roles. When everyone in the group had tried the prototype, they would then be asked to fill in a questionnaire.



Figure 8.1: *Test setups at AAU.*



Figure 8.2: *Test at UCC.*

8.2 Observations

Participants generally had a very short attention span when it came to reading the booklet. This led to confusion when they had to do the map calculations. Most of the time the test conductors also had to step in to help the VR user find the right handle on the cannon. Participants were still reluctant to do the math and often the conductors also had to help in this department.

As with earlier tests, users had trouble with using the Leap Motion because of its limited field of view. The participant would pick up an item and then move their hand out of the Leap's frustum. This causes the item to fall to the ground and was a source of frustration for many participants.

Test participants often used as much time as possible in the virtual environment. A few times the participant even had to be told to give the headset to the other participant. Very few participants experienced any motion sickness and the few that did was due to a technical glitch in the HTC Vive that slowly would make people shorter in the virtual environment.

8.3 Interviews

Four interviews were made during the testing period. Two were made during the tests performed at the AAU Demo day and 2 were made during the final experiments at AAU. The two versions of the prototype that were used have been

deemed close enough in function to allow these four interviews being compared and analysed together. Three of the four responses have been translated into English by the authors.

From the interviews it was clear that there had been a general frustration with the instability of the Leap Motion:

"It was OK but I thought it was annoying that you had to have your hands in front of you. It had to keep calibrating and it was difficult to use the small items but it was OK for the game itself. It was also difficult to turn the wheels because your hands would disappear when you looked at the dial."

"It was easier with the controllers since the hands were frustrating to use."

People generally liked the controllers. Some people even felt that the controllers were more fun to use because they were more stable:

"They were more natural and stable. It was easier but still sometimes difficult to grab the right thing. The controllers was more fun since you didn't have to think about where your hands were."

"It was very easy to control. It really helped the experience and it was more fun to interact with the objects."

"They work well. Easy to learn and worked as I expected."

"Very intuitive and it was fun to move objects around. It felt natural."

"It was easier to pick up stuff."

The interviewees felt that while it was fun to use the Leap Motion it would have been a much better experience if it had been more stable:

"It's cool to see your hands, if it worked better it would probably be more fun than the controllers."

"More immersive. It was fun to use your hands to do hand gestures but it was difficult to turn the wheel."

"It was fun to interact with your partner with the hands."

"More difficult. Fun to experience. It was weird to pick up things without having something in your real hand."

"Felt more natural but unstable. I got used to it quickly."

"I think it would be more fun to use the Leap, than the controllers, if it was as stable as the controllers."

"If the Leap was more stable it would be better than the controllers. As long as there is visual feedback then it doesn't matter if there is haptic feedback."

They also found the general experience pleasant and fun:

"It was fun and very different. It would be good at a museum or for teaching. It lacks something more to be a complete game."

"It felt unique and entertaining. Surprisingly pleasant and i felt no VR sickness."

"I love collaborative games. It was fun to communicate and then both having something to do."

They were also asked to give feedback on what they would like to change about the experience to make it better:

"I would have liked to have more information about the shot."

"A visual representation of the trajectory of the shot."

"I should be easier to throw things in general. It can be difficult to read the numbers."

"A time limit for more action."

Chapter 9

Results

9.1 Introduction

Total amount of participants was $N = 42$, where 35 valid participants were from the three days of testing at **Aalborg University Copenhagen (AAU-CPH)** and 7 valid participants from the one day of testing at **University College Copenhagen Sydhavn (UCC)**.

The rest of this chapter is going to display the results from the two different tests in order to clarify the data.

9.2 Gender

9.2.1 AAU-CPH

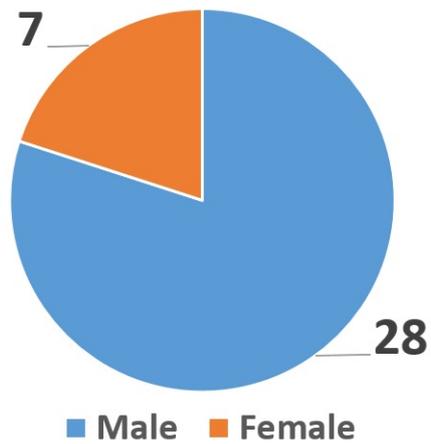


Figure 9.1: Amount of different gender among the Participants

9.2.2 UCC

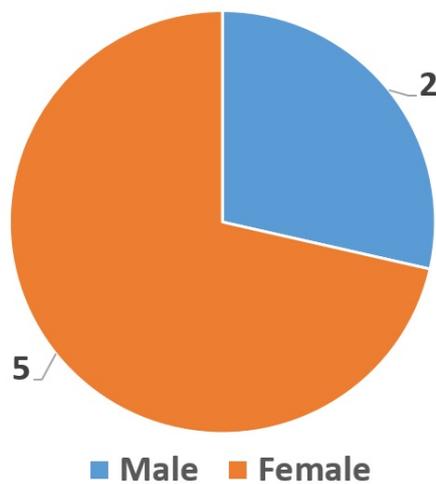


Figure 9.2: Amount of different Gender among the Participants

9.3 Educational Background

9.3.1 AAU-CPH

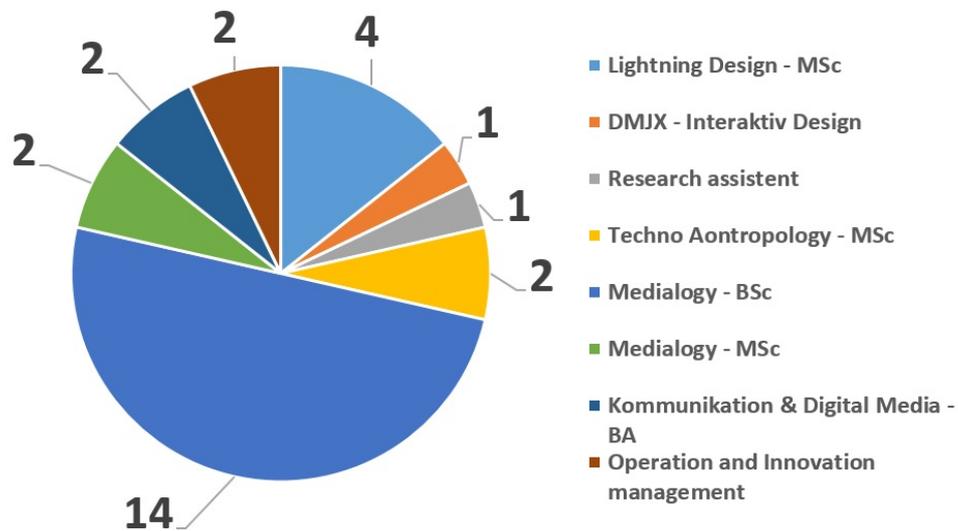


Figure 9.3: Amount of the participants' current education

9.3.2 UCC

UCC results are not shown as the only education at the campus is Pedagogy.

9.4 Difficulty experience

9.4.1 AAU-CPH

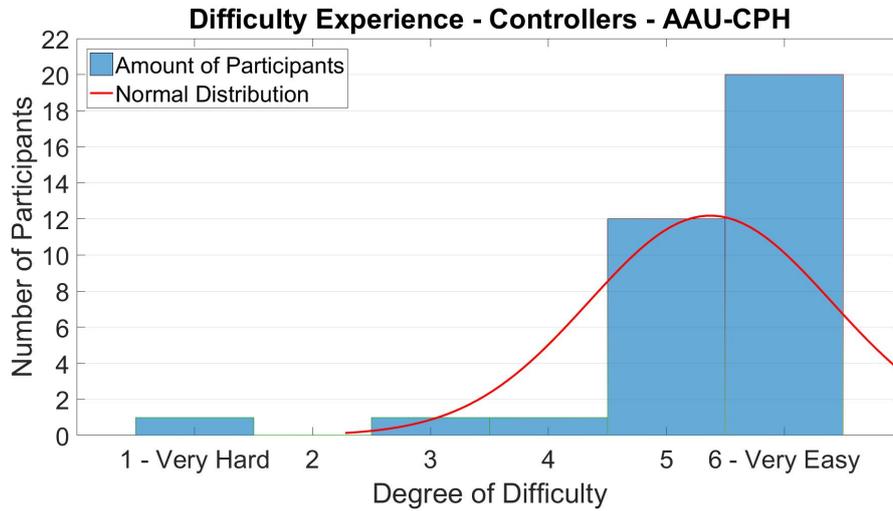


Figure 9.4: Difficulty Experience of the Controllers

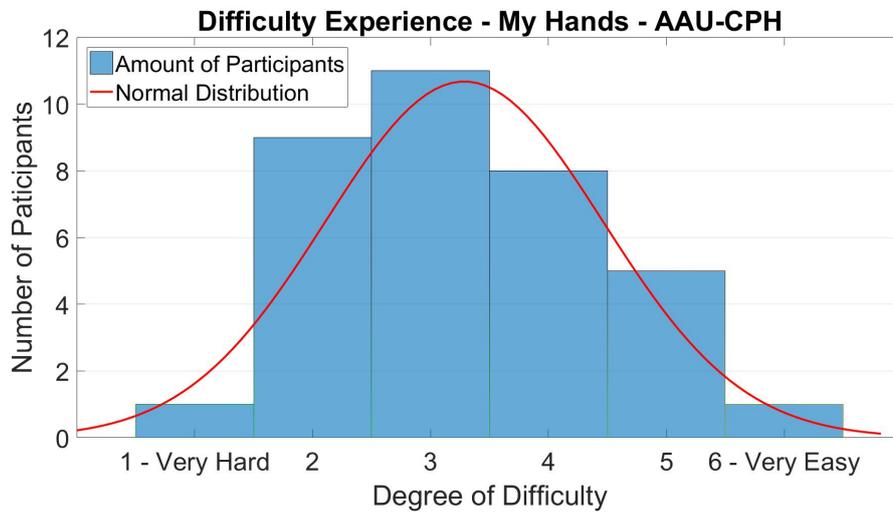


Figure 9.5: Difficulty Experience of the Leap Motion

9.4.2 UCC

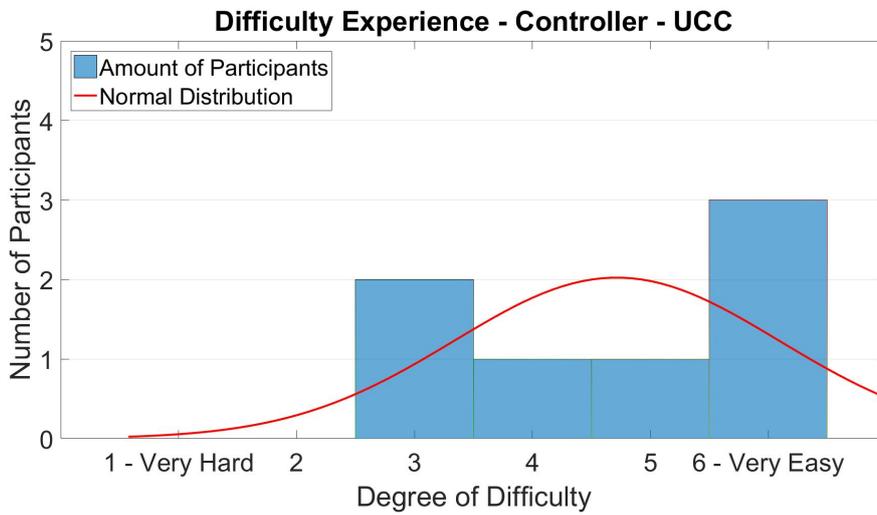


Figure 9.6: Difficulty Experience of the Controllers

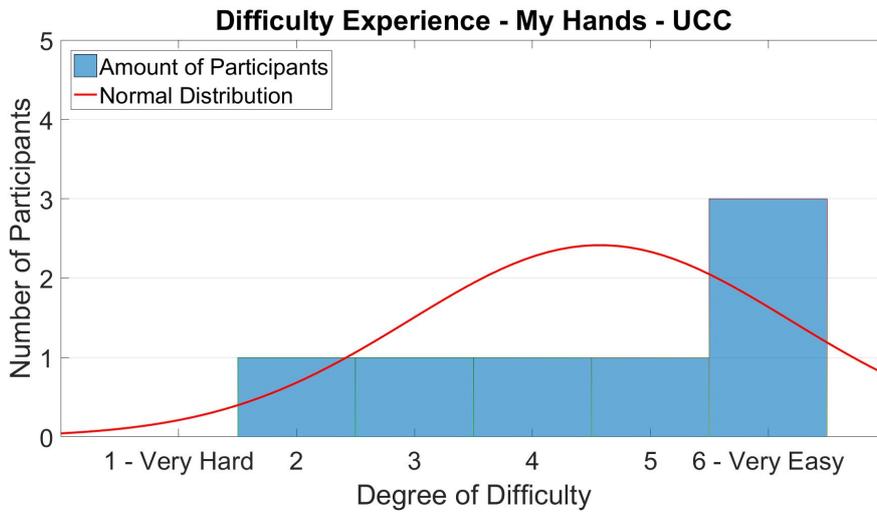


Figure 9.7: Difficulty Experience of the Leap Motion

9.5 User Experience

9.5.1 AAU-CPH

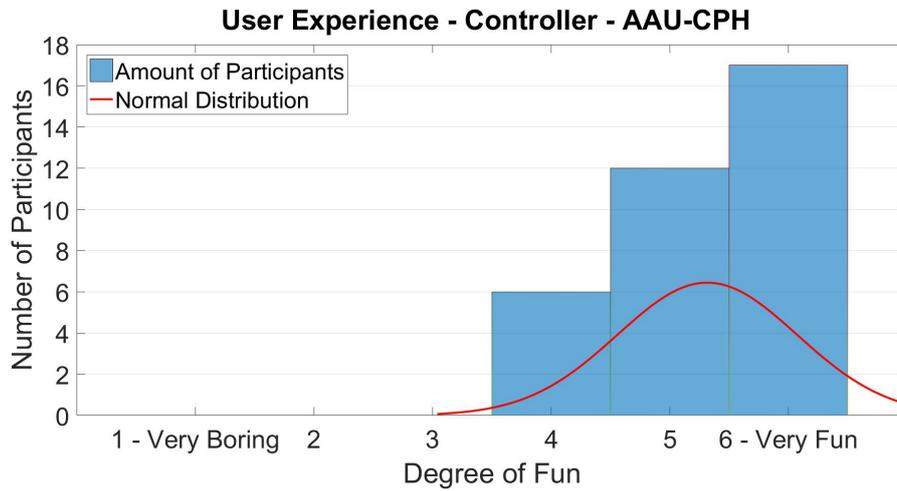


Figure 9.8: User Experience of the Controllers

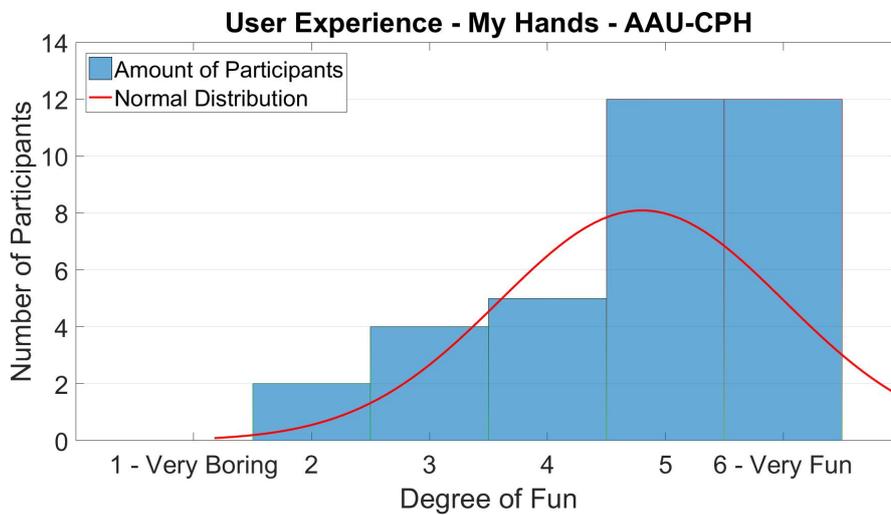


Figure 9.9: User Experience of the Leap Motion

9.5.2 UCC

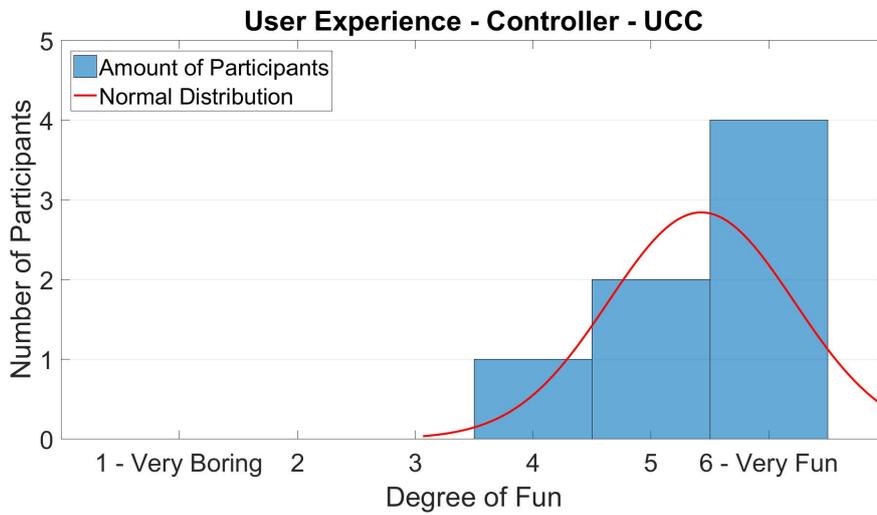


Figure 9.10: User Experience of the Controllers

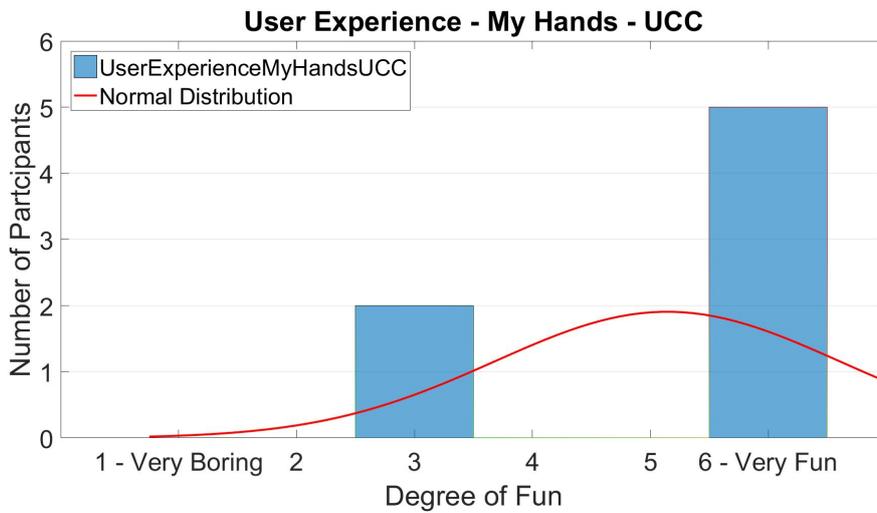


Figure 9.11: User Experience of the Leap Motion

9.6 Overall Experience

9.6.1 AAU-CPH

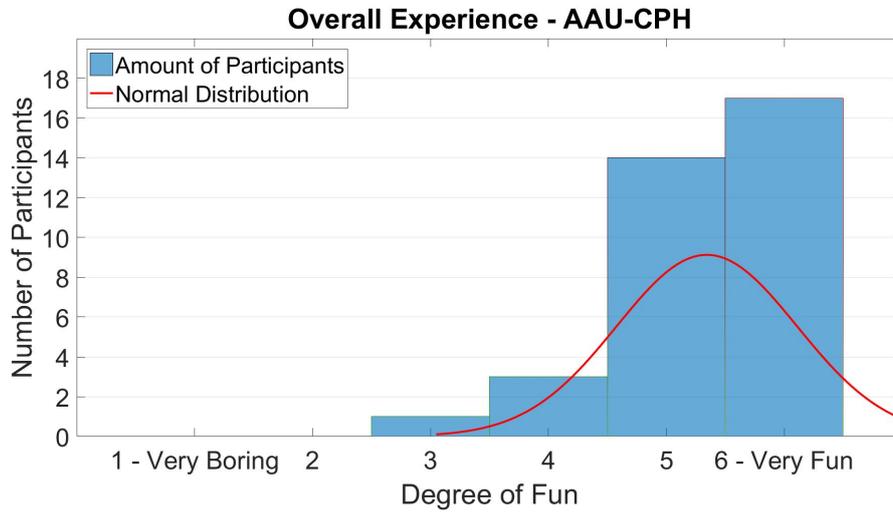


Figure 9.12: Overall User Experience of the Installation

9.6.2 UCC

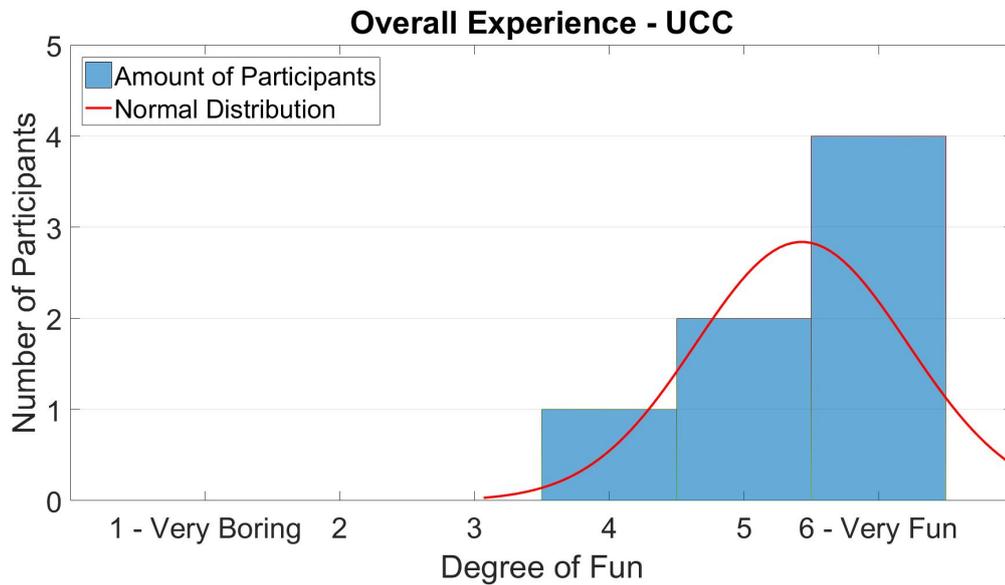


Figure 9.13: Overall User Experience of the Installation

9.7 Preferred Interaction Method

9.7.1 AAU-CPH

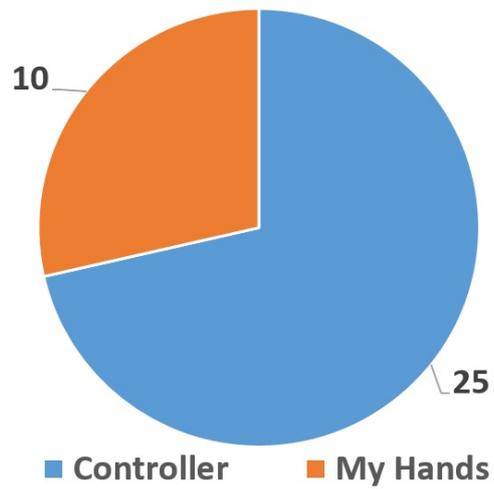


Figure 9.14: Preferred Interaction Method

9.7.2 UCC



Figure 9.15: Preferred Interaction Method

9.8 Frustration during the Experience

9.8.1 AAU-CPH

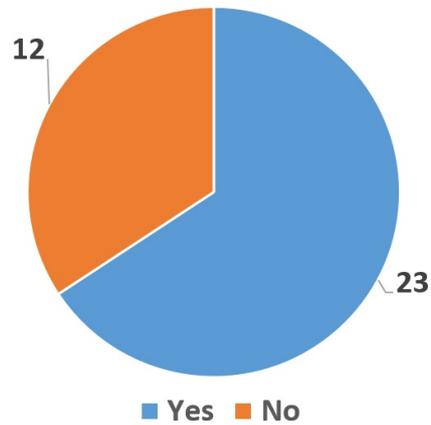


Figure 9.16: *Frustration experienced.*

See Appenndix for users' Answers

9.8.2 UCC

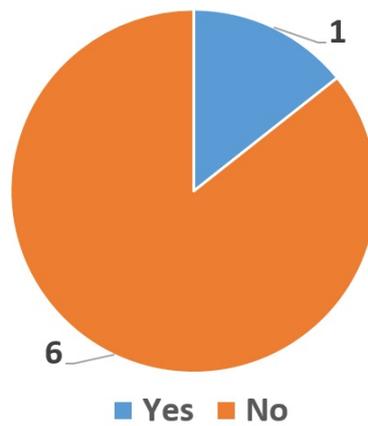


Figure 9.17: Frustration experienced.

See Appenndix for users' Answers

9.9 Statistical analysis

9.9.1 Hypotheses

The Wilcoxon Rank-sum test was used to test for equal medians between the difficulty and also the user experience of the different interaction methods. This checks if there is a significant difference in the two interaction methods based on the participants' answers. This means that if $H = 0$, medians are equal, as long the P value is below the 5% alpha value which is the chance of making a type 1 classification error. If $H = 1$, Medians are NOT equal as long the P value is above the 5% alpha value.

Difficulty Experience Controller vs Leap Motion - AAU-CPH

$P = 0$	$H = 1$
---------	---------

In this case the Null Hypothesis can be rejected. Which means that the experimental hypothesis has been confirmed, the following: *There is a significant difference in the difficulty experience between the HTC Vive controller and the Leap Motion.*

User Experience Controller vs Leap Motion - AAU-CPH

$P = 0.092$	$H = 0$
-------------	---------

In this case, there is not enough evidence to reject the null hypothesis, even though the p value is quite low.

Difficulty Experience Controller vs Leap Motion - UCC

$P = 0.974$	$H = 0$
-------------	---------

In this case, there is not enough evidence to reject the null hypothesis.

User Experience Controller vs Leap Motion - UCC

$P = 1$	$H = 0$
---------	---------

In this case, there is not enough evidence to reject the null hypothesis.

9.9.2 Correlation

Correlation was calculated using Kendall with the tail value set to "both" meaning that the correlation is not equal to zero.

See appendix for correlation matrix graphs.

Controllers - AAU-CPH

$P = 0.074$	$R = 0.285$
-------------	-------------

There is a small positive correlation, but the P value is not low enough to confirm it.

Leap Motion - AAU-CPH

$P = 0.021$	$R = 0.331$
-------------	-------------

There is a positive correlation between the participants user experience score and their difficulty score.

Controllers - UCC

$P = 0.971$	$R = -0.065$
-------------	--------------

There is no correlation between user experience and difficulty scores.

Leap Motion - UCC

$P = 0.095$	$R = 0.745$
-------------	-------------

There is a strong positive correlation, but the P value is not low enough to confirm it.

Chapter 10

Findings

Overall, test participants rated their experience with both control methods at approximately the same level. The controllers ranked a little bit higher, as there were fewer low ratings with them - the lowest rating for the controllers was 4, while the lowest rating for the Leap Motion was only 2. This means that both control methods are able to provide a mostly equal level of enjoyment from an objective point of view.

User difficulty experience however had a more noticeable difference. The controllers ranked slightly higher in this case, with the majority of users rating the difficulty of using them at a 6 (Very Easy), while the Leap Motion received the majority rating of only 3. This is to be expected, as there are a lot more ways that using the Leap Motion can go wrong since it relies on a IR sensor, which isn't normally able to update what it sees very fast and also cannot track what it can not directly see. The motion controllers on the other hand have full positional tracking that will always work anywhere inside the tracked area, which makes them a lot more reliable.

An attempt was made to try to find a correlation between how easy the participants found each method to use and how good they reported their user experience being when using that method. There was only enough data to find such a correlation with the Leap Motion during the AAU tests. This means that when the user felt that the Leap Motion was easy to use they also had a better experience. It could indicate that if the Leap Motion was more stable and easier to use, it could improve the user experience.

In regards to overall purely subjective preference between the two interaction methods, the majority of participants chose the controllers over the Leap Motion. This means that even though participants reported their overall experience with the

different methods at a relatively similar level, the difficulties that the Leap Motion presented could have possibly had an effect on their preference.

In order to see if the results might have been slightly skewed towards the controllers, the test group was separated into Medialogy students and other programme students. This might be because of the fact that most participants from AAU were from a technological background, more specifically the Medialogy study programme and were more familiar with similar technology. The participants could only be separated into these two groups because there was a significantly higher amount of Medialogy students as compared to other individual programmes. However, there was no significant difference in control method preference between Medialogy and other education students at AAU, as the amount of participants that preferred one over the other were approximately equal for each group as can be seen in figure 10.1. However, the questionnaire did not look into any previous background the participants might have had, so it is possible that some of them that were not currently in a Medialogy programme might have had previous experience in Medialogy.

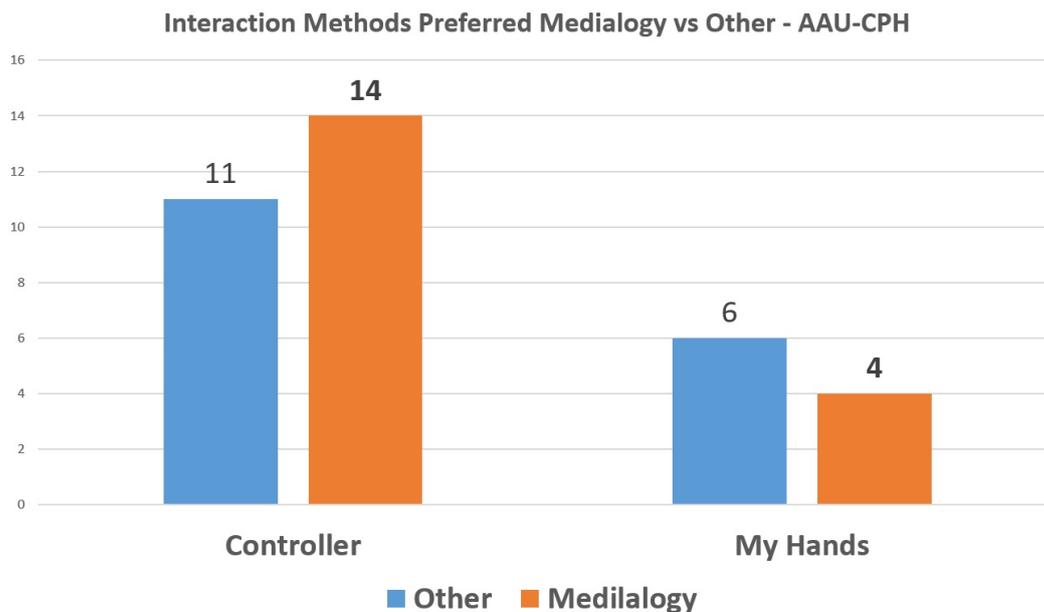


Figure 10.1: *Preferred interaction method based on education.*

In an attempt to find other patterns, another grouping of the test participants was made based on gender, separating the participants into groups of male and female. There was a distinction in control method preference based on the participant gender, as 10 out of 12 of female participants preferred the Leap Motion, while 24

out of 30 of male participants preferred the controllers, as shown in figure 10.2. However, this might not be indicative of a difference between the genders, as only 12 out of 42 of all the participants were female and most of the female participants were from UCC and thus had no technological background.

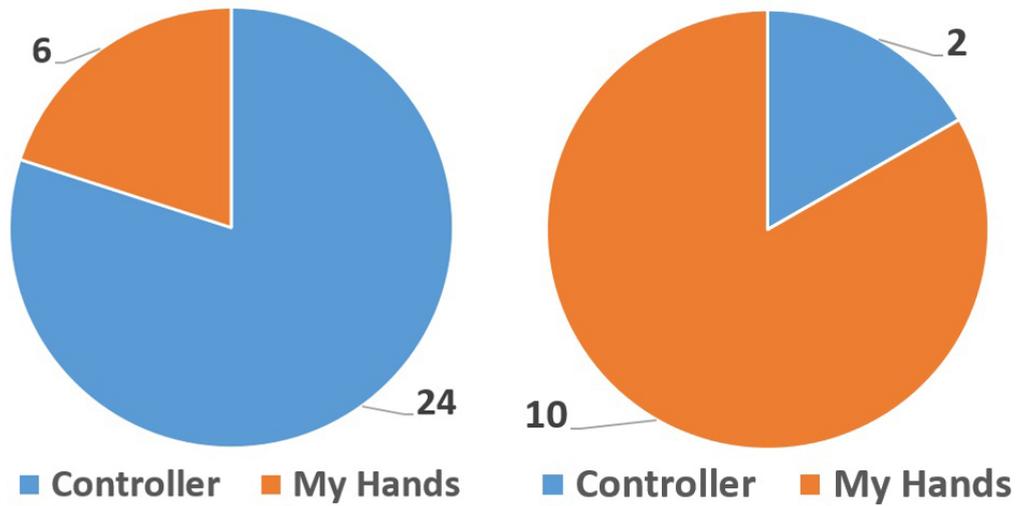


Figure 10.2: Preferred interaction method for male participants (Left) and female participants (Right)

Chapter 11

Discussion

11.1 Introduction

This chapter will be a discussion of the different aspects of the project. We will discuss possible solutions to problems concerning the prototype and the experiment and also the implications of the findings.

11.2 Methodology

The many new ways of VR interaction that have recently come along are still fairly untested. Our choice to look at it from a user experience perspective has so far been the correct way to go about it. It can be argued that it can be interesting to look into presence and immersion regarding VR interaction methods, but we did not deem our target group the correct one to ask these questions. However, a more thorough study should be able to conclude how VR interaction methods affect presence and immersion. The interviews gave good insight into people's frustrations with the Leap Motion. However, due to the design of the project, focus groups seem like an almost ideal fit and we regret not using this method. Attempting to perform tests in a real museum environment were not successful due to lack of test participants and scheduling concerns with the museum.

11.3 The prototype

The prototype lacked much variety, which could to boredom if played for an extended period of time. However, it served its purpose of being as short experience. A problem that came from the test setup was that the HTC Vive "Lighthouse" sensors were not properly mounted. They were attached to camera tripods, which did not provide enough stability and were relatively short, which lead to having to place them on tables, which lead to even more instability. This eventually lead to the sensors slowly tilting downwards which caused the player height in the VR environment to slowly change, which was disorienting.

11.4 Practicality

In regards to the practicality of using the different interaction methods in a museum environment, here is a list of pros and cons for each interaction method:

	HTC Vive controllers	Leap Motion
Pros	<ul style="list-style-type: none"> ● Full positional tracking ● Haptic feedback ● Buttons 	<ul style="list-style-type: none"> ● No external controller ● Low maintenance needs ● Easier to use
Cons	<ul style="list-style-type: none"> ● Battery life ● High maintenance needs ● Not as intuitive 	<ul style="list-style-type: none"> ● Small tracking area ● Software still in beta ● No haptic feedback

At the earliest convenience we should consult Greve Museum about this list and make sure they are informed about the requirements of the different interaction methods. They would also be able to give insight into what would work in a museum environment and what would not.

11.5 The results

From our findings it seems clear that both interaction methods could be used to create interesting interactive experiences in VR. They can even complement each other in certain situations. Finding that people felt that the Leap Motion

was harder to use was not a surprise but then also realizing that this did not necessarily reduce the users experience of fun was interesting. The novelty of the Leap hands seem to have overcome their instability as an interaction method.

Based on our experience of playing games and the observations, there seems to be a tendency that people who have prior game experience automatically associate efficiency with fun. Others might not care about how well they're doing and would have fun regardless.

During the tests at the fort and at the Demo day at AAU it was not possible to "win the game" by hitting the target. Even then, people liked the experience. It could indicate that the task of shooting the cannon is itself satisfying enough and even when users are told that they missed, sometime several times in a row, they leave the experience with a smile on their face.

Chapter 12

Conclusion

The final problem statement is as follows:

In a learning based, cooperative virtual reality game, how does the semi-natural control method of the HTC Vive controllers compare to the natural control method of the Leap Motion sensor in regards to user preference, usability and practicality?

During the project many tests were performed to compare how people reacted to the two different control methods. From these, it is apparent that there is no clear winner in this race. If someone is looking for a stable and precise way of interacting with a virtual environment, arguments could be made for choosing the Vive controllers. On the other hand, the Leap Motion provides a simpler hardware setup and a more novel experience. The choice might come down to practical considerations and then it is just a matter of picking the one that fits the situation best. Based on this project and the data gathered, our recommendation will be to try and weigh both methods against the specific user experience as well as practical considerations.

Chapter 13

Future Aspects

The semester project is winding down and coming to an end but that does not mean that the project as a whole will stop developing. This chapter will cover the aspects of the project we would like to work further with or that we could see other people being interested in looking into.

13.1 Further academic work

We are planning to take this project to ECGBL16 in Scotland to show off what is achievable in 4 months with consumer grade hardware. The whole subject of the right choice of interaction methods for a VR experiences might soon be blown wide open as many new hardware choices will enter the consumer market. There will be gloves and cameras and all different kinds of wearables and controllers; all designed as VR input devices. It would be interesting to see if some of these products might be better overall for certain types of VR installations.

13.2 Commercial possibilities

13.2.1 Historical Theme Parks

This project has tried to cover new ground as an interactive VR museum installation, with a historical theme. New kinds of theme parks are starting to emerge. According to an article by Tagmose, there is a theme park about the history of the vikings currently attempting to get funding. It will use interactive installations,

including VR, to teach about old Nordic culture. The research and testing of this product indicates that it would fit well into this kind of theme park environment.

13.2.2 Independent Game

We might also attempt to submit it to Steam's Greenlight service. If we succeed we could then release the application as a small free experience on the service for the public to use.

13.3 Potential of AR

As we have investigated the different interaction methods for VR installations, it could also be interesting to look into technologies like the HoloLens and Meta Glasses and see how this particular experience might function as a "Hologram". A lot of the interaction research for VR can also be used for AR based interaction as the AR headsets also use infrared cameras, similar to the Leap Motion to detect the user's hands. So it would be possible to re-create the application into these new devices and test the outcome of the experience, and see if it would serve the same experience as the VR application setup.

Bibliography

VR and Simulation Sickness. URL <https://docs.unrealengine.com/latest/INT/Platforms/VR/ContentSetup/index.html>.

Computer Base. <http://www.computerbase.de> virtuelle realität mit kompromissen und zwangspausen, 2015. URL <http://www.computerbase.de/bildstrecke/63596/>.

Harry N Boone and Deborah A Boone. Analyzing likert data. *Journal of extension*, 50(2):1–5, 2012.

Sean Buckley. <http://gizmodo.com> 15 insane indie game controllers for even crazier games, 2015. URL <http://gizmodo.com/15-insane-indie-game-controllers-for-even-crazier-games-1689808514>.

Sophie Charara. <http://www.wareable.com> samsung gear vr review, 2015. URL <http://www.wareable.com/samsung/samsung-gear-vr-review>.

Michele D. Dickey. *Aesthetic and Design for Game-Based Learning*. Routledge, 2015. ISBN 9780415720946.

ESA. Cydonia - the face on Mars / Mars Express / Space Science / Our Activities / ESA, 2006. URL http://www.esa.int/Our_Activities/Space_Science/Mars_Express/Cydonia_-_the_face_on_Mars.

farm8. farm8 website.

VR Forum. <http://www.youtube.com> leapdesk - oculus rift dk2 demo scene + leap motion, 2014. URL <https://www.youtube.com/watch?v=ah8t7hQL-bM>.

Peter Graham. <http://www.vrfocus.com> htc vive achieves fcc approval, 2015. URL <http://www.vrfocus.com/2016/01/htc-vive-achieves-fcc-approval/>.

- Eva Hornecker and Matthias Stifter. Learning from interactive museum installations about interaction design for public settings. In *Proceedings of the 18th Australia conference on Computer-Human Interaction: Design: Activities, Artefacts and Environments*, pages 135–142. ACM, 2006.
- Robin Hunicke, Marc LeBlanc, and Robert Zubek. MDA: A Formal Approach to Game Design and Game Research. *Workshop on Challenges in Game AI*, pages 1–4, 2004. ISSN 03772217. doi: 10.1.1.79.4561.
- Raph Koster. *A Theory of Fun for Game Design*. O’Reilly Media, 2nd edition, 2013. ISBN 9788578110796. doi: 10.1017/CBO9781107415324.004.
- Jonathan Lazar, Jinjuan Heidi Feng, and Harry Hochheiser. *Research methods in human-computer interaction*. John Wiley & Sons, 2010.
- Antonella Maselli and Mel Slater. The building blocks of the full body ownership illusion. *Frontiers in human neuroscience*, 7(March):83, jan 2013. ISSN 1662-5161. doi: 10.3389/fnhum.2013.00083. URL <http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3604638&tool=pmcentrez&rendertype=abstract>.
- R. P. McMahan, A. J. D. Alon, S. Lazem, R. J. Beaton, D. Machaj, M. Schaefer, M. G. Silva, A. Leal, R. Hagan, and D. A. Bowman. Evaluating natural interaction techniques in video games. In *3D User Interfaces (3DUI), 2010 IEEE Symposium on*, pages 11–14, March 2010. doi: 10.1109/3DUI.2010.5444727.
- M. Nabiyouni, A. Saktheeswaran, D. A. Bowman, and A. Karanth. Comparing the performance of natural, semi-natural, and non-natural locomotion techniques in virtual reality. In *3D User Interfaces (3DUI), 2015 IEEE Symposium on*, pages 3–10, March 2015. doi: 10.1109/3DUI.2015.7131717.
- NatMus.dk. National museum of denmark website.
- Jakob Nielsen. Iterative user-interface design. *Computer*, 26(11):32–41, 1993.
- Oculus. Oculus rift official homepage, 2016. URL <https://www.oculus.com/en-us/>.
- Katrin Schulze and Heidi Krömker. A Framework to Measure User Experience of Interactive Online Products. *MB ’10: Proceedings of the 7th International Conference on Methods and Techniques in Behavioral Research*, 2010:1–5, 2010. doi: 10.1145/1931344.1931358. URL <http://doi.acm.org/10.1145/1931344.1931358>.

Nathan Shedroff. Information interaction design: A unified field theory of design. *Information design*, pages 267–292, 1999.

Mel Slater. A Note on Presence Terminology. *Emotion*, 3:1–5, 2003. URL <http://people.cs.uct.ac.za/~dnunez/reading/papers/presenceterminology.pdf>.

Mel Slater, Bernhard Spanlang, Maria V Sanchez-Vives, and Olaf Blanke. First person experience of body transfer in virtual reality. *PloS one*, 5(5):e10564, jan 2010. ISSN 1932-6203. doi: 10.1371/journal.pone.0010564. URL <http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=2868878&tool=pmcentrez&rendertype=abstract>.

Amalie Tagmose. Danskere drømmer stort: Forlystelsespark om vikinger og nordiske guder skal være dobbelt så stor som Tivoli — Kultur — DR. URL <http://www.dr.dk/nyheder/kultur/historie/danskere-droemmer-stort-forlystelsespark-om-vikinger-og-nordiske-guder-skal>.

Christopher W. Totten. *An Architectural Approach to Level Design*. Taylor & Francis Group, LLC, Fairfax, 2014. ISBN 978-1-4665-8542-3. URL <https://www.google.dk/books?hl=da&lr=&id=Q0zMAwAAQBAJ&pgis=1>.

VRPill. <http://www.vrpill.com> okyeonjungsa vr museum gear vr experience, 2015. URL <http://www.vrpill.com/recent-news/okyeonjungsa-vr-museum-gear-vr-experience/>.

Wikipedia. Face On Mars. URL https://upload.wikimedia.org/wikipedia/commons/thumb/d/de/Face_on_Mars_with_Inset.jpg/425px-Face_on_Mars_with_Inset.jpg.