Master's thesis

NTNU
Norwegian University of Science and Technology
Faculty of Information Technology and Electrical Engineering
Department of Computer Science

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Oppdal VR – an Immersive Virtual Field Trip for Field Course in Physical Geography

Master's thesis in Computer Science
Supervisor: Frank Lindseth, Ekaterina Prasolova-Førland and Simon McCallum
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Abstract

Field trips are an important part of many university courses, but they also have many challenges. To accommodate this, virtual field trips (VFTs) can be created to simulate the experience. However, the creation of VFTs is time consuming and requires software engineering skills, something the content creators do not necessarily possess.

This project investigated how to create and use VFTs by developing two: Oppdal VR and the Penn State application. The original plan was to compare the two VFTs, as they differ in equipment and scalability. This was changed because of the Covid 19 lockdown. Oppdal VR was designed to use an omnidirectional treadmill, as this had not been used in a VFT before. The applications both use 360° images, but Oppdal VR also makes use of an area model with more interaction.

The data was gathered by distributing a video documenting Oppdal VR together with a questionnaire. This replaced user testing because of the Covid 19 lockdown. Additionally, domain experts from the fields of geography and VFT creation were interviewed. It was concluded that students and professors are positive to VFTs being used more in education. The consensus is that the VFTs should be used together with AFTs and not replace them. Additionally, the want for better tools to create VFTs was affirmed, and a pipeline documenting how to recreate topology from aerial scans and satellite images was created. This pipeline can be used to automate the creation of VFTs in the future.

The video documenting Oppdal VR can be viewed at:

`https://www.youtube.com/watch?v=24lFLQUjuew`

Sammendrag

Feltkurs er en viktig del av mange universitetsfag, men de har også mange utfordringer. Virtuelle feltkurs kan lages for å imøtekomme dette ved å simulere opplevelsen. Men, å lage virtuelle feltkurs krever tid og forutsetter programmeringskunnskaper, noe de som lager innholdet ikke nødvendigvis har.

Dette prosjektet undersøker hvordan man lager og bruker virtuelle feltkurs ved å utvikle to: Oppdal VR og Penn State applikasjonen. Den opprinnelige planen var å sammenligne de to virtuelle feltkursene fordi de er ulike i utstyr og skalerbarhet. Dette ble endret på grunn av Covid 19 nedstengningen. Oppdal VR ble designet til å bruke en omnidireksjonal tredemølle, ettersom de ikke har blitt brukt i virtuelle feltkurs før. Begge applikasjonene bruker 360° bilder, men Oppdal Oppdal VR bruker i tillegg en områdemodell med mer interaksjon.

Dataene ble samlet ved å distribuere en video som viser Oppdal VR , sammen med en spørreundersøkelse. Dette erstattet brukertesting på grunn av Covid 19 nedstengningen. I tillegg ble eksperter fra geografifeltet og utvikling av virtuelle feltkurs intervjuet. Det ble konkludert med at studenter og professorer er positive til å bruke virtuelle feltkurs mer i læringssammenhenger. Konsensus var at virtuelle feltkurs burde brukes sammen med faktiske feltkurs og ikke erstatte dem. I tillegg ble ønsket om bedre verktøy for å lage virtuelle feltkurs bekreftet, og det ble laget en stegvis oversikt for å gjenskape topografi fra luftskanninger og satellittbilder. Denne oversikten kan bli brukt til å automatisere produksjonen av virtuelle feltkurs i fremtiden.

Videoen som viser Oppdal VR kan sees på:

`https://www.youtube.com/watch?v=24lFLQUjuew`

Acknowledgements

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Contents

Glossary

AFT — Actual Field Trip
AR — Augmented Reality
GIS — Geographic Information System
HMD — Head Mounted Display
IVE — Immersive Virtual Environment
iVFT — immersive Virtual Field Trip
LiDAR — Light Detection And Ranging
NPC — Non-Player Character
VFT — Virtual Field Trip
VR — Virtual Reality
XR — Extended Reality

Chapter 1

Introduction

This section starts with the motivation behind this master's thesis. It then covers some of the research that has found VR to be a suitable medium for learning. The specialisation project this thesis builds on is then summarized, followed by the stakeholders, the target audience for the new application and the research questions.

1.1 Motivation

This master's thesis is a collaboration between the Innovative Immersive Technologies for Learning (IMTEL) virtual reality (VR) lab and the Department of Geography. The IMTEL VR lab and the Department of Geography are both from the Norwegian University of Science and Technology (NTNU). This project is a continuation of the Specialisation Project *Immersive Virtual Field Trip for Field Course in Physical Geography* [1], further described in Section 1.3.

Field trips are an important part of many university courses, especially in geosciences. The field trips do however have several drawbacks, like being costly and time intensive to perform. Virtual field trips (VFTs) can help to get the most out of the field trips, for example by aiding students to prepare. VFTs can also offer an alternative to people who are hindered from attending the actual field trip (AFT).

The field trip in question is for the course *GEOG - 2012 Field Course in Physical Geography* at NTNU. The course is an introduction to geography field work, teaching students about different land formations and concepts, and how they are created [2]. The course also focuses on preparing, planning and executing a field trip. This field trip is a two-hour drive from Trondheim and spans three days from a Monday morning to Wednesday afternoon. During this period the students spend about 10 hours in the field in addition to a separate excursion on the Tuesday. A lot of preparation is needed both before and during the field trip, and there are expenses related to transporting and housing the students for the duration of the trip.

There already exists several VFTs, like Google Expeditions [3] where an educator can guide others through images. There are also applications using more advanced interaction, like the Climate Quest [4] application from NTNU where the user has to outrun a rising ocean level while shooting objects that are bad for the climate. A new application was created for this project, combining a VFT with more advanced interaction. This new application, named **Oppdal VR**, was developed until its testing in the beginning of May. Like the Climate Quest, it trades scalability for immersion, meaning it requires more advanced equipment. The most notable of this equipment is the Virtuix Omni omnidirectional treadmill. This was chosen in an effort to raise the engagement of the user, and because omnidirectional treadmills have not been used in VFTs before. Oppdal VR focuses more on providing an opportunity to explore and learn, instead of invoking feelings around a topic like the Climate Quest. Oppdal VR was developed using *open source* resources, meaning they are open and free to use.

As VFT is an established term, there is also existing research on this subject. One of the leading sources of the research is Penn State University [5]. From a news article at Hypergrid Business [6] the research is summarised as collecting data on both actual- and VFTs, concluding that students are very positive to the VFTs. In an article from Penn State in 2017, Klippel and others [7] evaluated the current development of VR field trips. They found that many of the earlier barriers had been overcome and that VR technology was ready to become more prominent in the market. Their research is however centred around VFTs where interaction is mostly limited to looking around inside 360° images. The focus of this master's thesis is therefore to combine images with a reconstructed landscape and introduce more interaction with the virtual world.

1.2 VR, Learning and Engagement

As the presence of XR equipment increases, so too does the available research and experience with the technology. Several research papers have emerged that regard XR as improving learning outcome compared to traditional methods, like reading books and articles.

A. Vishwanath et Al [8] studied the introduction of learning with VR by using Head Mounted Displays in a learning centre in a low-income area in India. They worked with 16 students for several weeks, creating VR applications that covered several fields of study. They observed that the use of VR lead to the students displaying more curiosity in the field and being more inquisitive.

D. M. Markowitz [9] performed field studies and experiments with over 270 students. They also noted that students were more curious and knowledgeable after being exposed to VR learning applications. They also found a correlation between how much the students explored the space of the VR applications and how curious and inquisitive they became of the subject. This can be an indication that a more engaging experience offers better learning and sparks curiosity.

Researchers at the University of Southern Queensland [10] used VR equipment to teach human anatomy to 24 students from both nursing and business disciplines. Their findings were that VR was a highly preferred medium for learning. They did not find any significant difference between the two preferences of the two groups. They attribute this popularity of the VR to its visual nature. This is based on their survey of the preferred learning medium for high school students. The survey found that the graphic media is twice as preferred as verbal explanation, which again is three times as preferred as reading.

Researchers at University of Warwick [11] compared the learning outcome for 99 participants, using one of three medias. They compared VR to video and textbooks of the same information and found VR to give the best learning experience. The participants using VR reported higher engagement, positive feelings and also better performance for remembering the content.

Overall VR appears to improve the learning experience compared to traditional media. This improvement seems to come from the visual and engaging nature of VR.

1.3 Immersive Virtual Field Trip for Field Course in Physical Geography

This master's thesis builds on a specialisation project [1] that was done in the autumn of 2019. The project started with a literature review documenting the current state of VR technology, VR and learning and VFTs. The literature review was used to identify research questions for the project, with some that have been carried over to this thesis. The actual field trip was also attended to get the experience and capture the 360° footage. The project also researched into recreating topology from LiDAR scans. This recreation is currently dependent on three programs. A lot of time was used in the beginning of the specialisation project to discuss the content and main gameplay elements of the new VFT with the domain experts. This was used to identify the requirements of the new VFT. In the end a simple prototype of Oppdal VR was created and evaluated by domain experts in geography. Additionally, the 360° images were sent to Penn State who created a simpler VFT with the functionality of jumping between the images. The VFT from Penn State was tested during the specialisation project and iteratively developed with Penn State. At the conclusion of the project, the requirements were identified, the outline of the reconstruction pipeline was documented, a literature review had been performed, research questions had been created and partially answered, the 360° footage had been captured and two prototype VFTs had been produced (one of them by Penn State).

1.4 Stakeholders and Target Audience

The identified **stakeholders** for the master's project are as follows:

- **Scientific Community and General Public**
  In order to give the best possible contribution to the scientific community, the project has focused on following the norms and best practices of research. The project is also meant to contribute to the general public, both indirectly through the research and directly by the creation of Oppdal VR for those who want to experience the field trip.

- **Institute of Geography**
  As the main collaborator on the project, the Institute of Geography guided the learning outcome of the project. As the eventual users of the new application, they also provided input when prioritising features during development.

- **IMTEL**
  As IMTEL is concerned with immersive technologies for learning, this thesis is directly related to their work. The project can add to their existing research on VR as well as contributing to best-practices and methodologies. Additionally, Oppdal VR is made with code quality in mind to allow for later expansion and reuse of assets.

The **target audience** of Oppdal VR are the students of GEOG - 2012 Field Course in Physical Geography. As this is an introduction course to geography field work, the content of the application is possibly on a level where the general public can learn something as well.

1.5 Research Questions

The research of this project is centred around developing and testing the **Oppdal VR** application. LiDAR, a type of laser scanning, was used to recreate a topological model of the area. Stereoscopic 360° images was included to show the actual landscape. Game design was used to create interactive tasks to motivate and engage the users. Oppdal VR should originally be compared to the simpler, more scalable application supplied by Penn State university. They would use the same images and feature the same content. This had to be changed because of the Covid 19 lockdown limiting development and the user testing.

The research questions are based on the current literature on the topic of VFTs, and have been constructed to further investigate certain aspects or look at different perspectives. These aspects to be investigated are mainly how to create and use VFTs and how engagement affects the learning outcome. The research questions are based on those found in the Specialisation Project [1], but have been modified as the project has unfolded. They are accompanied by explanations to make them clearer. The research questions are:

- **RQ1 -** *How can a VFT be developed?*
  What are the tools and methods required for developing a VFT? Is it possible to automate parts of the process?
- **RQ2 -** *What game design theories apply and should be used in a VFT application?*
  As the goal is to investigate if a more interactive application can provide a better learning outcome, it is important to choose the right kind of interactivity. This will be done by exploring literature and determine which elements that best improve the experience.
- **RQ3 -** *Can VFTs be valuable support tools for courses with field trips?*
  Contributing to the current research on the field, the goal is to investigate how useful a VFT can be as a supportive learning tool to a university course and how to make best use of them.
- **RQ4 -** *Can the use of interactive elements in a VFT lead to a better learning outcome than passive applications based on displaying images?*
  Expanding on the current research on the field, this will focus on comparing an application with little interaction, to one with more to see if there are differences in learning outcome.
- **R5 -** *Can VFTs have educational value for the general public outside of their academic discipline?*
  Oppdal VR is developed with students from geography as its target audience. How is the learning outcome for people without a background in geography?

Chapter 2

Method

In this section the research method is described. The development methodology for the new VFT is also presented, together with the development plan and changes because of the Covid 19 lockdown.

2.1 Oates' Model of the Research Process

This master's thesis use Oates' [12] Model of the Research Process. Simplified, Oates' model describes the research process divided into seven main parts. The research model, with the parts used for this project highlighted, is presented in Figure 2.1 below:

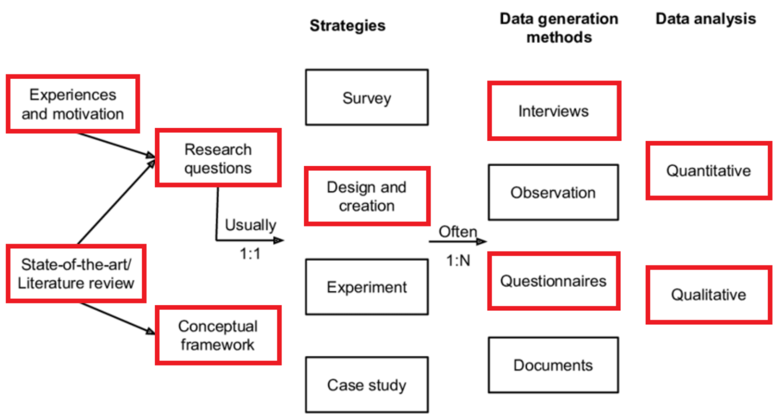


Figure 2.1: Oates' Model of the Research Process [12] with the parts used for this project highlighted

The four first parts of the research process are stated to be more or less the same for all types of research. These are the four "boxes" to the left of Figure 2.1: Experiences and motivation, Research questions, State-of-the-art/Literature review and Conceptual framework. The personal experience and motivation combined with a literature review create the research questions. The literature review also leads to the conceptual framework that *"makes explicit how you structure your thinking about your research topic and the process undertaken"*. The remaining three categories have elements that can differ depending on the type of research. As indicated in the figure, one research question typically leads to one strategy, whereas a strategy can lead to several methods of data generation.

2.2 Research Method of this Master's Thesis

The research method was identified in the Specialisation Project [1]. This master's thesis conforms with Oates' model, with the four first parts present. This means that the project starts with existing experiences and motivation from the author. Combined with the literature review of the topic, research questions can be made. Additionally the conceptual framework of the terminology and relations take form and will be present throughout the thesis. The **Design and Create** strategy was used to answer all of the presented research questions. This was done by developing the new Oppdal VR, then testing it.

Two data generation methods arise from the strategy: **Interviews** and **Questionnaires**. People with VR equipment were invited to download and test Oppdal VR, whereas people without VR equipment were supplied a video demonstrating the application. The video focused on showing the application as-is without explaining anything around it. This was to potentially uncover if anything in the application was unclear as it is meant to be a stand-alone application. The video was made from gameplay footage with commentary on top, walking through the application to demonstrate it to those who could not test it.

The data analysis approach is both **qualitative** and **quantitative**. The questionnaires are the sources for the quantitative data analysis, whereas the interviews supply data for the qualitative data analysis.

2.2.1 Questionnaire

Two questionnaires were created for the data collection. A simple preliminary questionnaire was made for the prototype testing, and a larger questionnaire was made for the main data collection. The simple questionnaire asked about demography, whether or not the user had learned something, as well as questions from the User Experience Questionnaire (UEQ) [13].

The questions for the main questionnaire were based on several other questionnaires with similar goals. Questions about individual differences, learning and enjoyment were taken from a study from Penn State in 2019 comparing the effect of VFTs to a control group [14]. Questions about control, active learning, and perceived learning effectiveness were taken from a study from 2010 investigating how desktop virtual reality enhances learning [15]. Questions about opinions on VFTs were taken from another Penn State paper from 2019 investigating VFTs in a geoscience course with elevated 360° images. The idea behind combining these questions is thoroughly investigate the learning and opinion aspect of the VFT. The questions were used with a five-point Likert scale [16] to create a quantitative and standardised data set.

In addition to questions about learning, the System Usability Scale (SUS) [17] was used. This a relatively simple, but effective way of testing the usability of a system. It uses ten questions answered with a five-point Likert scale. The Likert answers are then used to calculate a usability score between 0 and 100. The score is divided into three categories where 51 and lower is indicates poor usability, around 68 is average and 80.3 and upwards is considered good. The questions from the UEQ in the simple questionnaire were also included. These questions were meant to evaluate the application itself, not necessarily its usefulness as a learning tool. The main questionnaire can be viewed in Appendix C.

2.2.2 Interview

The questions for the semi-structured interview were not taken from any literature, but created to find qualitative answers to the research questions. The questions were about evaluating the app itself and about VFTs and their possible usage in education. The questions explored how to use VFTs, the perceived effect on motivation and the interest for tools make them. The questions for the interviews can be viewed in Appendix A.

The interview subjects were domain experts with different areas of expertise. In total 7 interviews were performed. There were 3 geography professors at NTNU, 1 scientific assistant in Geography, 1 VR expert from the IMTEL lab, and 1 professor and 1 PhD graduate working on VFTs at Penn State.

The interviews were analysed iteratively. They were first transcribed from audio recordings, but only statements instead of word-for-word transcription. The transcriptions were then cleaned by removing duplicate statements within interviews, moving statements to their respective questions and removing examples that were made to back up statements. Finally, thematic analysis [18] was used to structure the answers. This analysis encodes statements with labels to make them more comparable. The labels can then be gathered in themes. The results from the interviews are gathered in said themes and presented in its entirety in Appendix B, with the main points presented in Section 6.3.

2.3 Data Handling

When performing user tests, the data handling needs to be in accordance with the General Data Protection Regulation (GDPR) [19]. In order to make sense of the regulations, an article from medium.com was used, as it details the best practices of data handling. Following these practices, as little sensitive information as possible was collected. For the general questionnaires this meant none, focusing the questions on the application. The questions about the testers were also generalised, e.g. by placing them in age groups instead of asking for exact age. The questionnaire also avoided text answers, as this can be regarded as sensitive information. A group application was sent to the Norwegian Centre for Research Data to allow the for the collection data.

2.4 Development Methodology: MVP

The development methodology for creating Oppdal VR is the Minimal Viable Product (MVP) approach. Techopedia [20] defines this at the technique where a product is developed containing the bare minimum functionality. Then, more features are added, typically through feedback produced by the prototype. This technique has two major benefits for this master's thesis. Firstly, it allows users to be included as early as possible in order to better guide the product from an early part of the development, when changes are less cumbersome to make. Secondly, it allows for more dynamic planning, as the development includes new tools and frameworks. This is likely to result in less time used for planning and re-planning due to the uncertainty in time estimates. The plan for the MVP is a prioritised list as can be seen below in Section 2.4. The line separates the ”must-have” features of the MVP from the ”if-time” features that can be added.

Table 2.1: Prioritised List of Features for the Application

1	Recreate topology from LiDAR
2	Re-texture topology
3	Decorate area with prefabs of trees and grass
4	Implement image viewer for 360 stereoscopic images
5	Implement a task for pointing at different parts of the images
6	Implement different models for ”Storskredet” and a way to switch between them
7	Implement more game mechanics
8	Improve prefab decorations of the area

The development also followed a continuous iterative approach. When possible, the application was tested on students to gather feedback. This feedback was used both to improve the features already present, but also to discover new functionality that could be added. The development had no set length for the iterations. This was to, as explained above, focus time on development instead of planning.

2.5 Development Plan

As the project followed the **Design and Create** strategy from Oates, the project plan was divided into four parts: preparation, iterative development, data collection and data analysis. The project plan is presented in the milestones below:

Table 2.2: Plan with Milestones for the Project

Time	**Milestone**
End of January	Finalise the shape of the terrain and finish the MVP feature list
End of February	Finish decorating the area with prefabs, incorporate image viewing and decide on game mechanics to be used in co-operation with domain experts
End of March	Implement game mechanics
Middle of April	Finish prototype development and freeze code. Finish questionnaires for testing and tasks for the Penn State application.
End of April	Finish user testing with students and finish interview questions for domain experts
Middle of May	Finish user testing, interviewing domain experts and finish comparison of applications
10 of June	Finish structuring and analyse collected data, finalise the project and the report, export any assets that can be reused by IMTEL

The plan was generally followed, but with around three weeks of delay following the Covid 19 lockdown. This delay moved the start of the data collection to the beginning of May and the end of the data collection to the end of May, and also extended the project to the 24th of June.

2.6 Changes due to Unforeseen Events

In the spring of 2020, the COVID 19 virus led to a lockdown of the IMTEL VR lab and the rest of NTNU. This caused some changes to be made to the both the project and the application:

- **Testing** had to be done remotely instead of at the VR lab. The app had to be tested by whoever had VR equipment at home. Additionally, a video demonstrating the application was sent out to get feedback from those without VR equipment, especially students that attended the field trip in the autumn of 2019.
- **Focus** of the project had to be shifted from comparing two applications to evaluating Oppdal VR. This was because of the small possibility of people having two kinds of headsets available at home, the challenge of properly showing the differences via video. The comparison was intended to use the LEAGUE framework presented in Section 3.3.3.
- **Teleporting** was added as an alternative way of movement in Oppdal VR. This was to make it easier for home testing, both in development and evaluation, as no one had an omnidirectional treadmill at home.
- **Research questions** had to be changed towards the end of the project. This mainly led to removing a research question about how well the omnidirectional treadmill worked, as access to the lab was restricted. A new research question, R-5, was also added because of the changes to testing. By sending out the video and the questionnaire, a broader audience was the data source, allowing to look at differences in learning outcome between geography students and the general public.

Chapter 3

Background

This section presents the relevant theory of the VR and its concepts. It also looks at the hardware used for VR and topology reconstruction in the project. A framework from Penn State for evaluating VFTs is also described, and will be used to compare different existing solutions and Oppdal VR. Theory about VFTs is then presented, followed by game design theory.

3.1 VR and Hardware

A literature review of the theory and technology of the field was conducted in the Specialisation Project that this master's thesis continue from. The following section is therefore directly extracted from said project [1], with the exception of Section 3.1.2, Section 3.3.3 and Section 4.8 that have been added in this project.

3.1.1 Different Types of Realities

When discussing different types of environments, it is natural to bring up the *Reality - Virtuality continuum* [21], seen in Figure 3.1. This continuum was proposed in a paper by *Paul Milgram* et al, discussing the different types of realities and environments.

The continuum describes a continuous transition from the Real Environment, through the Mixed Reality into the Virtual Environment. Within the Mixed Reality (MR) there are two opposite realities: Augmented Reality (AR) and Augmented Virtuality (AV). Both include objects from the Real- and Virtual Environment, but differ in that AR is mainly the Real Environment with elements from the Virtual Environment, whereas AV is mainly the Virtual Environment with elements from the Real Environment. Because the transition is continuous it can become difficult to separate a reality as either AR or AV if it falls in between.

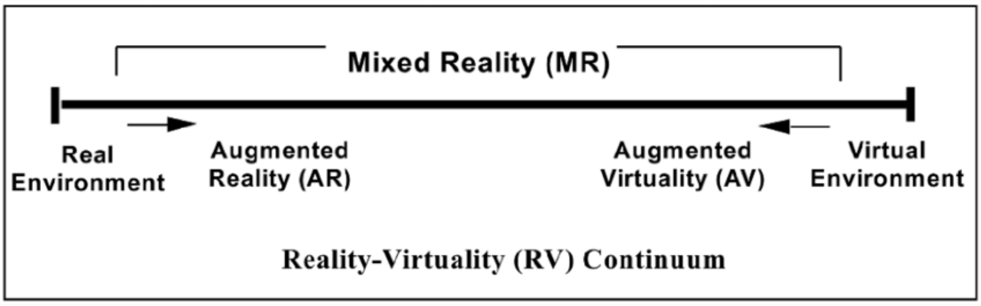


Figure 3.1: The Reality - Virtuality Continuum by Paul Milgram [15]

Extended Reality (XR) has been made as an umbrella term that incorporates both Mixed Reality and Virtual Reality [22]. This has been done to make a separation between the Real Environment and the rest that have some form of technology involved. The hierarchical relations of the different realities and environments have been illustrated in Figure 3.2.

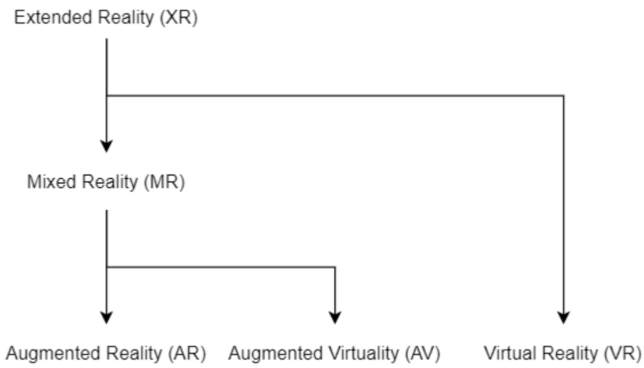


Figure 3.2: Categories of Extended Reality

Oppdal VR is entirely a VR application.

3.1.2 Virtual Reality

Even though Virtual Reality (VR) has become part of the mainstream media market, a brief introduction and evaluation is presented here.

According to the Oxford Dictionary [23], VR is:

> *"The computer-generated simulation of a three-dimensional image or environment that can be interacted with in a seemingly real or physical way by a person using special electronic equipment, such as a helmet with a screen inside or gloves fitted with sensors."*

Another dictionary, Merriam Webster [24], defines VR as:

> *"An artificial environment which is experienced through sensory stimuli (such as sights and sounds) provided by a computer and in which one's actions partially determine what happens in the environment"*

In the book *The VR Book* by Jason Jerald [25], VR is defined as:

> *"[...] a computer-generated digital environment that can be experienced and interacted with as if that environment were real."*

The definitions start to paint a picture of VR. A common denominator between these is a **computer-generated environment**. Furthermore, they all agree on this environment being **interactive** to some degree.

The Three I's of VR

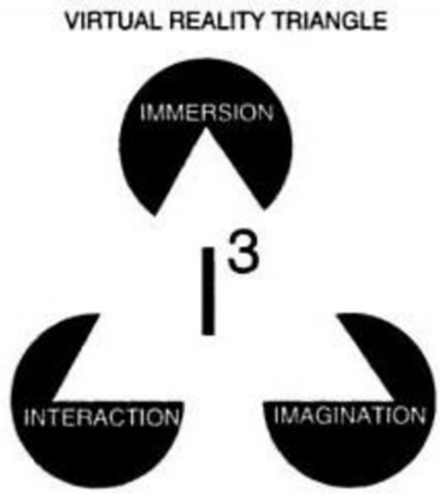


Figure 3.3: The Three I's of Virtual Reality from "Virtual Reality Technology" [26]

The term VR is also explored in the book *Virtual Reality Technology* [26]. It is stated that VR has three features: immersion, interaction and imagination. As seen in Figure 3.3, the features are represented as equally important to the nature of VR. The book defines VR as:

> *"Virtual reality is a high-end user-computer interface that involves real-time simulation and interactions through multiple sensorial channels. These sensorial modalities are visual, auditory, tactile, smell and taste."*

From this definition, the immersion and interaction feature of VR are clearly rooted. An important point made by the book is that VR should not be defined based on the devices that are used, but rather its purpose and function. The last feature, imagination, is less obvious at first glance. Although not directly present in the quoted definition, VR is not only an interface, but has applications for real life problems. Because of this the imagination of the user is important for the performance of the simulation, and therefore the extent of which the application can solve a real problem. The imagination is also necessary to perceive non-existing things. This an important point as VR, although immersive, cannot perfectly simulate the reality. The imagination bridges this gap by letting the user invest themselves in the simulated world, not unlike the suspension of disbelief when reading a book or watching a theatre play. This is demonstrated by the perceived, non-existing triangle in Figure 3.3.

VR Sickness

An unfortunate side effect that can arise from VR is VR sickness. VR sickness manifests itself in the same way as motion sickness, and can cause nausea, vomiting and trouble maintaining balance [27]. According to researchers from the University of Newcastle Australia [28], motion- and VR sickness might be the same thing, although other studies disagree. In the University of Newcastle study, the researchers exposed volunteers to uncomfortable physical and visual tests and found large similarities in how the volunteers reacted. As the nature of VR- and motion sickness is still debated, there are a few theories to the cause of the problem [29]:

- **Sensory Conflict Theory**
  This theory is the most widely accepted and states that the sickness is caused by a mismatch between visual and physical input. This happens when the eyes perceive motion, especially acceleration, and the body senses no force acting upon it.

- **Eye Movement Theory**
  The theory suggests that the eyes move unnaturally compared to real life when using VR. This happens because the images change differently to what the eyes expect and therefore strains the eyes, causing discomfort.

- **Postural Instability Theory**
  This theory builds on the theory that sickness occurs when humans are unable to keep their posture [30]. On the assumption that this is correct, VR sickness is explained by small subconscious actions done to anticipate movement shown visually that is not present physically. These actions throw the user of balance, disrupting the posture and causing discomfort.

- **Evolutionary Theory**
  This is not as much a separate theory as more of a possible explanation of *why* the sickness is present. It states that the symptoms are evolutionary reactions made to survive poisoning that can cause inconsistent impressions, which is a common denominator in the different theories.

Regardless of the true reason for VR sickness, the theories provide similar ways to avoid it. The main points are to keep the players as stable as possible, avoiding acceleration and providing stable frames of references to help spatial orientation.

3.1.3 Head Mounted Displays

As the project will only include VR from the Reality - Virtuality Continuum, it will, as VR for the largest part does, be based on head mounted displays (HMDs). Generally speaking, these are headsets that contain one or two screens and lenses capable of projecting individual images to each eye. Oppdal VR will use the HTC Vive Pro, whereas the Penn State application runs on the Oculus Go.

HTC Vive Pro

This headset setup consists of two base stations, two controllers and the headset itself. The base stations are installed in a room to accurately track the players head and hand movements. It is not a stand-alone HMD, and must therefore be connected and run on a computer. The headset has a resolution of 1440 x 1600 per eye on dual AMOLED screens, adding up to a total of 2880 x 1600. It Has a refresh rate of 90Hz and includes an integrated microphone and headphones. It won the award ”VR Headset of the year” in 2018 and can be regarded as high-end hardware. [31]

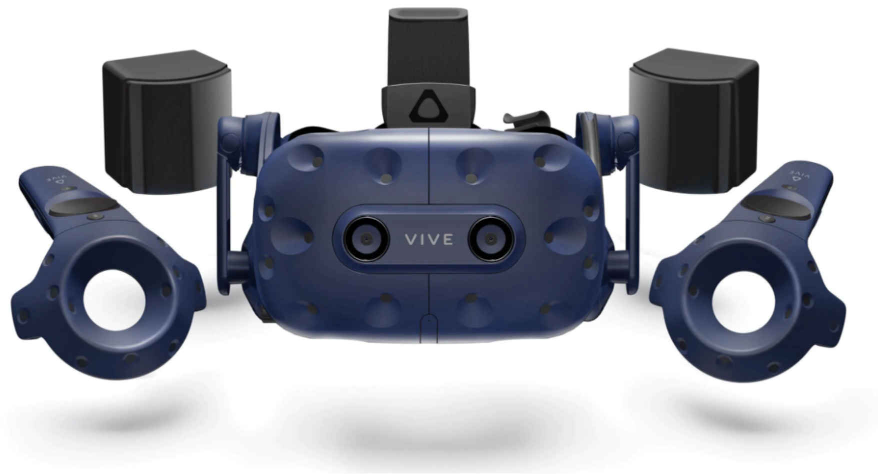


Figure 3.4: The HTC Vive Pro Head Mounted Display with Controllers and Base Stations, from Vive's Website [31]

Oculus Go

In contrast to the HTC Vive Pro, the Oculus Go is a stand-alone HMD, meaning that it has internal processors and does not need to be connected to a computer. It consists of the headset and one controller. It also has integrated speakers to offer an audible experience [32]. This means that is a lot more portable and easier to set up, but at the cost of lower processing power and less accurate controller tracking. The Oculus has one 538 pixels per inch (ppi) screen with a resolution of 2560 x 1440 [33]. It was launched in 2018, so it is from the same era as the HTC Vive Pro, but with a different purpose and price range.

Figure 3.5: The Oculus Go Head Mounted Display with its Controller, from Oculus's Website [32]

3.1.4 Omnidirectional Treadmill

The Omni is an omnidirectional treadmill developed by Virtuix [34]. It is compatible with the HTC Vive Pro head mounted display. As illustrated in Figure 3.6 it consists of a concave surface, low friction shoe covers and a harness to keep the player in place. The Omni tracks the orientation of the player from the harness, as well as the feet movement by wireless sensors connected to the shoe covers. The movement of the feet is then transformed to in-game motion. The Omni can be integrated by a software development kit (SDK) [35]. Virtuix supplies SDKs for both the Unity and Unreal game engine. From Omni's web pages it can be seen that the applications featured are all of the entertaining type. This is indicative of it being mainly used for games and not for education, like VFTs.

Figure 3.6: Omni - the Omnidirectional Treadmill by Virtuix [34]

3.1.5 LiDAR

A LiDAR scanner is a Light Detection And Ranging equipment that can record the surface area of objects [36]. The LiDAR consists of a laser emitter to send laser pulses, a scanner to precisely record the reflected laser pulses, and a GPS receiver to accurately track the position of the LiDAR equipment during scanning. By very precisely recording the time between laser pulses that are sent out and reflected back, the speed of the pulses (light speed) can be used to calculate the distance between the LiDAR and the object reflecting the laser. By repeating this process of sending and detecting laser pulses in different directions, a point cloud will be generated that represent the surface area of the object. Because of the GPS receiver the LiDAR can be moved during scanning, which allows for aerial scanning from helicopters and planes.

LiDAR equipment can be divided into two categories depending on the laser type they use to scan the surfaces. *Topographic* LiDAR systems uses near-infrared lasers. This type of laser will, as explained above, be reflected by surfaces and give a point cloud reminiscent of what one would see from the point of view of the LiDAR. *Bathymetric* LiDAR uses a green light laser. This laser is better at penetrating water, opening the possibilities for mapping sea- and riverbeds where the topographic LiDAR would only return the surface of the water.

As LiDAR equipment bases its sensing on laser pulses it can also exploit one of the properties of light: not everything is reflected [37]. Illustrated in Figure 3.7 is the effect when some of the light from the LiDAR is reflected back while the rest continues, penetrating through the object or missing it entirely. This is especially common in vegetation, as leaves are thin and do not cover the entire area. This allows one pulse to give multiple readings, which can be used to gather information about the vegetation itself or filter it out to get an isolated view of the ground.

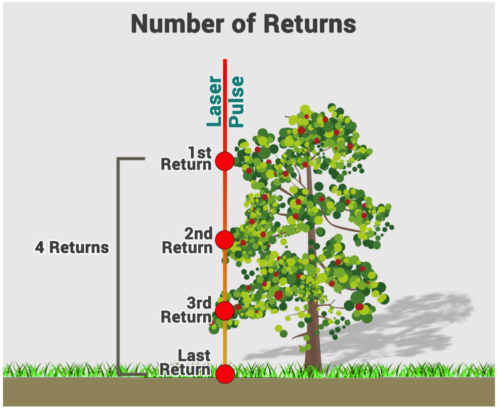


Figure 3.7: Laser Pulses Partially Reflecting on- and Penetrating Canopy, From GIS Geography [37]

3.2 Virtual Field Trips

Virtual field trips (VFTs) are becoming more common in STEM[1] education, where the areas of study that implement them the most are geosciences and architecture. Virtual field trips are, as the name implies, simulations of field trips meant to either support or replace the actual field trip. Even though they become more prominent, there are still numerous constraints to creating and using these applications. Many of the constraints revolve around the lack of tools that allow domain experts to create the VFTs themselves [38]. Despite these challenges, some evidence points towards the VFTs having positive impacts on the courses. Research and experiments done by Kathy Jackson and more [39] at Penn State University states that other research done on the effectiveness have shown inconsistent result, whereas they themselves found very positive impact on learning, enjoyment and grades. The inconsistent results can indicate that the topic needs more research.

The researchers at Penn State later compared three types of field trips: actual field trips (AFTs), immersive virtual field trips (iVFTs) using VR and desktop virtual field trips (dVFTs) [40]. They found that the iVFT with VR was more engaging than its desktop counterpart, but gave the same learning outcome. Curiously both the iVFT and dVFT scored better than the actual trip when measuring perceived learning outcomes. Their two key points out if these results are that VFTs can

[1]Science, Technology, Engineering and Math

contribute positively to learning outcome, but does not necessarily have to be in VR.

Similarly, research at Inland Norway University of Applied Sciences [41] investigated immersive virtual environments (IVEs). Immersive virtual environments are defined, by an article from two American universities investigating psychological experiments [42], so that "*the user is perceptually surrounded by the VE (Virtual Environment*". This is very similar to the definition of virtual reality, but with focus on the environment itself instead of the person's reality. It is also related to immersive virtual field trips that try to replicate real areas, but with learning as its main objective. The Inland researchers [43] compared a real walk with a sitting VR application and a treadmill VR application. Their findings were that the sitting and treadmill VR applications performed similarly, but both suffered in enjoyment because of VR sickness. The immersive virtual environments still performed well on presence and replicating the real walk. This points to the quality of applications, and their ability to avoid VR sickness, to be an important challenge of immersive virtual environments and immersive VFTs.

3.2.1 VR Virtual Field Trips

Virtual field trips are not necessarily in VR, but VR is the focus of this master's project. The current trend when it comes to the use of VR VFTs is to use low-level VR applications, meaning VR applications that run on low-cost hardware and that can be created with relatively low-cost and effort [44]. An opportunity that is present in these low-cost VR applications is to have multiple users experiencing the field trip at once. This is something that can be taken into account when implementing more advanced applications, as they will likely be used with an audience of other students.

3.2.2 Framework for Evaluating Virtual Field Trips

In their research article, A. Klippel et al [45] propose a framework for assessing immersive learning experiences, specifically iVFTs. In essence this framework is a two-dimensional plane where the VR technology is rated on one axis, and the content of the VFT is rated on the other axis. An overview of the research framework is presented in Figure 3.8

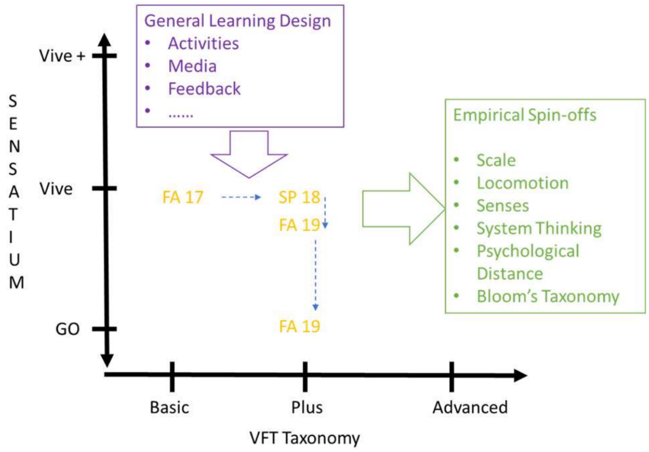


Figure 3.8: Overview of the Research Framework for Immersive Virtual Field Trips from Klippel et al [45]

The VR technology is evaluated on the vertical axis on the left in the research framework overview above. *SENSATIUM* is a term coined by A. Klippel et al, which is an acronym for the **SEN**sing - **S**c**A**lability **T**rade-off cont**I**nu**UM**. As seen in Figure 3.9, *SENSATIUM* is a continuous scale where scalability goes from high to low, and sensing goes from low to high. Both are dependent on how advanced the equipment is. This shows that higher levels of sensing trades off against the ability to scale the application.

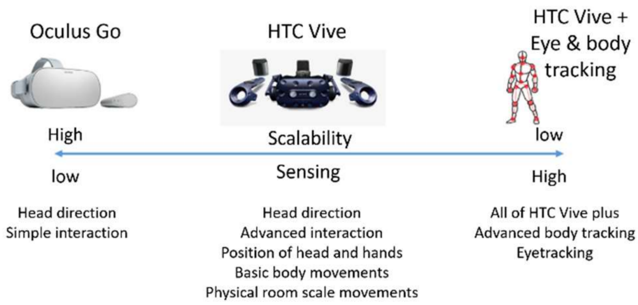
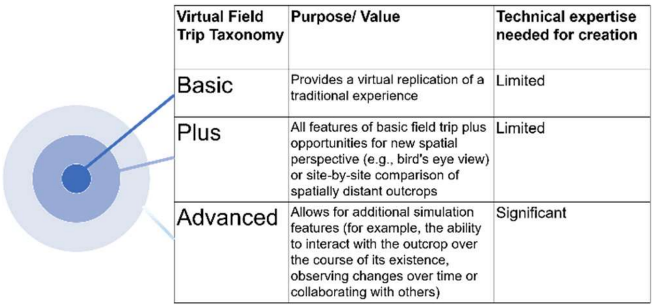


Figure 3.9: SENSATIUM, the **SEN**sing - **S**c**A**lability **T**rade - off cont**I**nu**UM** from Klippel et al [45]

The SENSATIUM continuum shares some similarities with degrees of freedom (Dof) [46]. DoF refers to the amount of directions the user can move, and is divided into 3 and 6. 3-DoF allows the user to freely look around in three dimensions (pitch, yaw and roll) and 6-DoF allows the user to also move around in three dimensions (x, y and z). In this way, low sensing on the SENSATIUM continuum can correspond to 3-DoF, and medium sensing corresponds to 6-DoF. High sensing is not represented in DoF, as e.g. an omnidirectional treadmill won't allow the user to move in more dimensions than is already available with e.g. teleporting from controllers, which is regarded as medium sensing.

On the horizontal axis of the research framework overview (Figure 3.8) the content of the iVFT is evaluated. The continuous scale goes from *Basic*, through *Plus* to *Advanced*. This rating of iCFTss, called the *taxonomy* of iVFTs, was also established by A. Klippel et al. The *taxonomy* is explained in Figure 3.10



Virtual Field Trip Taxonomy	Purpose/ Value	Technical expertise needed for creation
Basic	Provides a virtual replication of a traditional experience	Limited
Plus	All features of basic field trip plus opportunities for new spatial perspective (e.g., bird's eye view) or site-by-site comparison of spatially distant outcrops	Limited
Advanced	Allows for additional simulation features (for example, the ability to interact with the outcrop over the course of its existence, observing changes over time or collaborating with others)	Significant

Figure 3.10: Taxonomy of Immersive Virtual Field Trips from Klippel et al [45]

The different levels of Virtual Field Trips are explained in the figure, but can be summed up as Basic being replication of a real field trip, Plus adding new spatial perspective and Advanced adding simulations and / or models, allowing access to realities that does not exist in the real field trip.

3.3 Game Design and Evaluation

In order to make Oppdal VR as interactive and engaging as possible, game design theory was researched. The relevant theories are presented here. These are theories and heuristics for creating good games in general, as well as more specific theory related to educational games, which one can argue also adhere to VFTs.

3.3.1 Lazzaro's Four Fun Keys

In chapter 20 of the book *"Game Usability: Advice from the Experts for Advancing the Player Experience"* [47], Lazzaro presents the theory that there are four types of fun to be found in video games. She goes on to describe that players have a tendency to transition between three of these, which implies that successful games have at least three of the four types of fun present to cater to the players desires throughout the gaming sessions. The four types of fun are:

- **Hard Fun**
  This is the type of fun most people think of when talking about video games: the fun of the challenge. It is explained that the Hard Fun follows a cycle where the player meets a challenge and builds up frustration, followed by a phase named *Fiero* when the player overcomes the challenge. Afterwards comes a phase of relaxation where the player can bask in the glory of their achievements before the cycle starts again. It is important that the challenge is correctly balanced to give the player the right amount of frustration before the *Fiero*. It is also important to allow the player to ”cool down” before starting to build up more frustration.

Figure 3.11: The Hard Fun Cycle by Lazzaro [47]

- **Easy Fun**
  This type of fun is connected to the story and the wonders of the world within the game. It is the type of fun one has when exploring mystic worlds or the curiosity when trying to uncover the hidden story of a forgotten incident. Like the Hard Fun, Easy Fun is also a cyclic behaviour where curiosity leads to a surprise that causes wonder. This is followed by a cool-down phase of relief before the cycle continues. Also similar to Hard Fun, the surprise in Easy Fun must be balanced in order to keep the content familiar enough to be engaging, but also surprising enough.

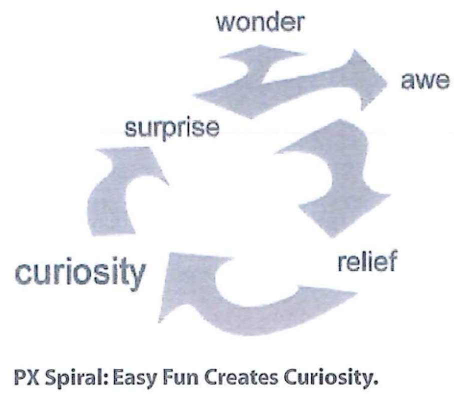


Figure 3.12: The Easy Fun cycle by Lazzaro [47]

- **Serious Fun**
  This type of fun is defined as when the game "create something of value outside of the game itself". Examples of this can be to use games to relax after a hard day at work, to learn rhythms or, in our case, to learn something. Serious Fun can lead to more motivation as the game is not just played for fun, but can improve the player in some way.

- **People Fun**
  People Fun is the fun related to the social aspects of games. This type of fun is very obvious in multiplayer games with both cooperative and competitive interaction between the players. It does however not explicitly require other players, as it can also be achieved through the use of non-player characters (NPCs).

3.3.2 Heuristics For Designing Instructional Computer Games

A set of heuristics for designing instructional computer games are given by Malone in his article from 1980 [48]. The heuristics describe essential characteristics divided into three categories:

Challenge

Similar to Lazzaro, Malone states that an instructional game must be challenging. He goes forth to describe heuristics for the goal that shall be completed, stating that it should be:

- Obvious
- Compelling
- Of the appropriate difficulty

- Offering performance feedback

By following this heuristic, the player should end up with knowing what to do, as well as having a motivation for doing it. It should be within the players ability to do it, and they should have a clear indication of how well they perform, both when under- and over performing.

In addition to the goal, the game should have an uncertain outcome. This is to ensure that it becomes exciting, as a game where one always wins or always lose can quickly become boring. This uncertain outcome can be achieved by having:

- Variable difficulty setting
- Multiple level goals
- Hidden information
- Some randomness

The difficulty can be set manually by the player, or be set automatically by the performance of the player. The difficulty is important as it can greatly affect the self-esteem of the player, which again will influence motivation. Having multiple level goals is another way to balance the difficulty, by making obligatory tasks of the goal easy, but offering challenging optional goals. The hidden information is also a great way to make the outcome of the challenge uncertain by revealing information along the way. Randomness can both aid the hidden information, as well as increasing the difficulty.

Fantasy

Fantasy in games can be used to make them more compelling, but can also be used as a means of challenge by having tasks that require players to use their fantasy. An important note is that different fantasies are compelling to different people, and should therefore be chosen based on the target audience.

Malone differs between two different kinds of fantasies: extrinsic and intrinsic. The extrinsic fantasy is dependent on the player skill, where the example in the article is the game Hangman where the visuals depend on the actions of the player. The extrinsic fantasy is also dependent on the skill, but the skill is also dependent on the fantasy. This means that the fantasy is used together with the skill. The example here is a game of darts where the trajectory, angles and force must be fantasised by the player, thus being used in conjunction with the skill.

Emotion is also discussed under the Fantasy category. It is a very powerful element, but it is also very hard to use. By emotionally engaging the player with e.g. NPCs in the game, the goal can be perceived as more compelling, and the feedback will have a stronger impact on the player. Because of the difficulties of using emotion, there are no general way to approach this element.

Curiosity

Curiosity mainly stems from having the right amount of *informal complexity*. The goal is to have the player comprehend the situation, but also having some uncertain or hidden information. Curiosity is divided into two categories: sensory and cognitive. The sensory curiosity instinctively captures the players attention, usually by playing visual or audible ques. This plays on the "lizard brain" of humans that automatically seeks out movement and flashing lights. The cognitive curiosity however relies on missing information. This has some similarities with Lazzaro's Easy Fun in that the missing information should be surprising to engage the player and motivate further progress.

3.3.3 The LEAGUE Framework for Evaluation

The LEAGUE framework [49] was developed to simplify the evaluation of game-based learning. The framework was created by reading literature on the topic and extracting common features. The features were then placed in a three-level hierarchy. The gist of the framework is that game-based learning can be divided into six dimensions (that make up the name LEAGUE): **L**earning, **E**nvironment, **A**ffective Relations, **G**ame Factors, **U**sability and Us**E**r. These dimensions are then further decomposed into factors and sub-factors. Finally, the sub-factors can be evaluated through metrics. The metrics is the lowest level in the model and the parts that can actually be compared. The five metric types are: scores, time, number of occurrences, rating or opinions. The idea of the framework is to use this hierarchical model when planning, designing and evaluating games to ensure a universal language. An overview of the hierarchy is presented in Figure 3.13:

Figure 3.13: LEAGUE Hierarchical Structure and Components from Tahir et al [49]

Chapter 4

Related Work

As discussed in Section 1.1, VFTs using VR is already present and available as commercial products. A quick introduction to some of the most similar or relevant solutions are presented, as well as summary comparing the different applications on key factors. The existing applications were identified and described in the Specialisation Project [1]. Applications are chosen based on the criteria below, where the first is mandatory and at least one of the other two other must be present.

- **Application have to be in VR**
- Application is a VFT
- Applications uses an omnidirectional treadmill

Although not all applications are VFTs, the framework for evaluating VFTs from Section 3.2.2 has been used to rate them on their use of player input and in-game functionalities.

4.1 Penn State University Application

Penn State University has created an application for showing images taken from a field course. The application provides the player with an aerial map of the area where image locations are highlighted. Players can then select images from the map, from a menu available when in image mode and by using arrows within the image to move to adjacent images. The selection is done by aiming a reticle with the head, then pressing a button on the controller. The application only support monoscopic 360° images, limited by the intended hardware: Oculus Go and Oculus Quest. The application does allow for multiple users at the same time, where one of the users can guide the other users through the images while explaining the content. As the application only tracks head movement, it has low sensing on the SENSATIUM continuum. It also aims to replicate the AFT without use of new perspectives or models, categorising it as basic in the iVFT taxonomy.

This is the VFT that should be compared to the Oppdal VR before the changes following the Covid 19 lockdown. It has been made in collaboration with Penn State. Specifications for how to capture and mark the footage was supplied from Penn State and the images were sent back in monoscopic format, geotagged and with indications of which images transition to which. The development was incremental with a prototype being tested with domain experts and reworked based on their feedback.

4.2 Google Expedition

Google Expedition is a smart phone application available on both Google Play and the App Store. As can be read on Google's own pages about the product [3], the application offers both VR and AR functions. When used as VR, one leader can guide others through 360 images and see where the participants are looking. This is done using cardboard headsets with the smart phone placed into it. When using the AR functionalities, objects can be displayed and viewed from all angles making the participants walk around a fixed physical location in the classroom. This is done without the cardboard headset by viewing the room through the camera of the smart phone

Google Expedition also has the ability for domain experts to create their own VFTs with the Tour Creator. It can create tours from 360° images, 180° images or images from Google Street View. When it comes to the headset version it does not appear to use any 3D models of the areas. As the headset is based on smart phones and does not have any controllers, the interaction is limited to head movement. Google Expeditions does not inherently provide any new spatial perspectives or additional simulations. It is however possible to use images with a bird's eye view, leaving it as basic or plus on the iVFT taxonomy, depending on the specific VFT in question. The application allows for the use of textboxes in order to convey information, as can be seen below in Figure 4.1.

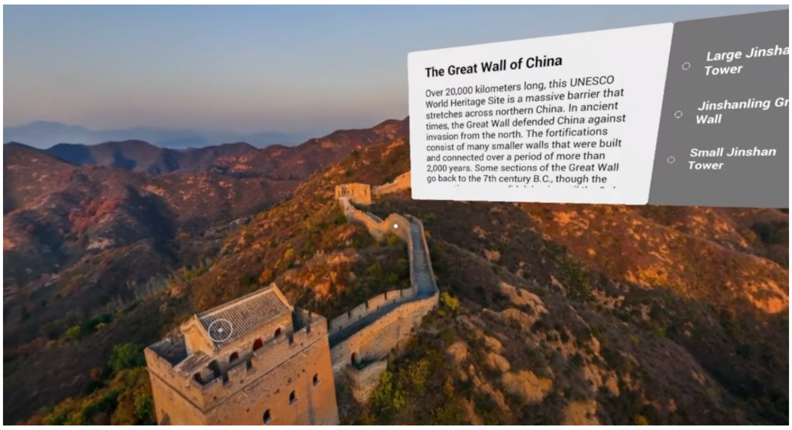


Figure 4.1: A Bird's Eye View Image with a Textbox from Google Expeditions [3]

4.3 Google Earth VR

Google Earth VR is another VR application by Google, and is described on their website [50]. It creates a 3D model from satellite imagery that the user can traverse. It is however, in line with their 2D application Google Earth, a service that does not allow the user to scale up or zoom the model to a human sized perception. Because of this, its model recreation is also somewhat coarse, working best when reproducing larger objects like mountains and valleys.

The application allows the user to walk or fly around the model, giving a natural bird's eye perspective of the environment, as can be seen in Figure 4.2 below. There are currently no additional simulation features, so Google Earth VR is placed in the plus category of the iVFT taxonomy. As it is made for VR headsets with controllers, it ranks in the middle of the SENSATIUM continuum, allowing for interaction with both head- and controller tracking and controller input.

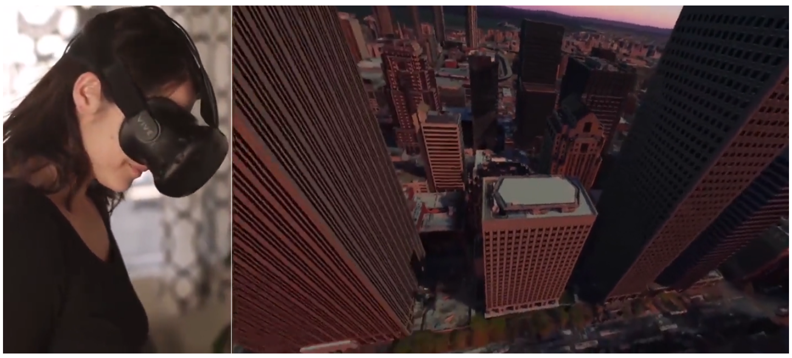


Figure 4.2: A User Looking Around in Google Earth VR [50]

4.4 Climate Quest and Player Program

One of the most recent papers produced about the Virtuix Omni is a bachelor project from NTNU [4]. The team of students created three applications. In *Climate Quest* the player can run around in the Trondheim city centre while the ocean level is rising. The player is tasked with shooting objects with negative impact on the climate, converting them to greener solutions. Shooting the objects also decrease the water level making it safe to navigate the lowest point in the area. In addition to the water level rising, points were given for shooting the targets. Points were also based on the time the player used. The team also performed user tests, which gave very positive feedback. The tests were primarily centred around testing the application, not if the user changed their feelings towards climate change. The Climate Quest uses high sensing on the SENSATIUM continuum. Although it does not allow for new spatial perspectives, its simulation of the rising seawater puts it in the plus category of the iVFT taxonomy.

The Bachelor project also included an application for shooting generic targets, called Player Program. The targets can either only give points, or display text as well. The application is meant as an educational tool where the text can display knowledge to help students learn. Like the Climate Quest, this application also takes time into consideration when calculating points to create a more engaging experience.

The third application is a desktop application for placing the targets for the learning tool mentioned above. This allows e.g. a professor to place the targets and assign custom text to some of them. This will then be exported as a `.json` file that can be imported by the learning tool application. This is an important tool as it bridges the gap between domain experts and software development, although it is currently only available for the Trondheim city centre.

4.5 Stanford Ocean Acidification

Another application that explores climate change comes from Stanford University [9]. In the experiment the effect of the VFT as a medium for learning about ocean acidification is explored. This is one of the more interactive applications that were found, consisting of four studies with four different applications or versions of applications. The user is placed underwater and can interact with the environment like fishes and corals, as can be seen below in Figure 4.3. Depending on the application the user also has one of several avatars to represent their body in the application. The interactions are related to the nature of the VFT, with some of them being counting species with a time limit in different environments. Another of the applications have the user embody a coral and have to collect calcium bicarbonate ions from the water in order to grow. Another test that was conducted was to have a fish bump into the player while a person taps the player gently in real life with an object to simulate the feel of the fish. Overall, the four different studies use both headsets and controllers, placing them on the medium part of the SENSATIUM continuum. When it comes to the iVFT taxonomy, it can be argued that the Ocean Acidification offers a new spatial perspective by submerging the user underwater. In any case it also shows different surroundings depending on the acidity of the water, placing it in the advanced category.

Figure 4.3: A User Immersed in the Ocean Acidification from Stanford University [9]

4.6 Inland Simulated Nature Walk

The research at the Inland University, discussed in Section 3.2 - Virtual Field Trips, produced an application based on 360° video. Although it might not be considered a virtual field trip, it was included because of its work on reconstructing a real area and includes a treadmill. The simulated nature walk [43] could either be experienced while sitting down, or while walking on a one-directional, mechanical treadmill. The treadmill setup is shown below in Figure 4.4. A 360° video of walking along a trail plays in its entirety and, in the case of the treadmill, the walking speed is determined by the user. The application did not have any user input, neither from controllers nor the treadmill. This places it as low on the SENSATIUM continuum. The application also did not go beyond replicating the the real trip, putting it in the basic category of the iVFT taxonomy.

Figure 4.4: A User Experiencing the Nature Walk from Inland University [43]

4.7 The Virtual UCF Arboretum

Created by the University of Central Florida, the Virtual UCF Arboretum [51] is a highly detailed virtual recreation of wild nature. The different botanical models in the application are of high precision and created to be as realistic and correct as possible. A view from the application can be seen below inFigure 4.5. Different tools were used to achieve the high details, like historic geographic information system (GIS) data, field observations, images, measurements and drone footage. The application is also integrated with a website, offering more information on e.g. different tree species. It also offers different modes of transportation, like walking, teleporting and flying. The flying allows the player to get a different point of view of the area, which will put it into the plus category of the iVFT taxonomy. The application takes input from both the headset and controllers, giving it a medium rating on the SENSATIUM continuum.

Figure 4.5: The Virtual Arboretum from University of Central Florida [51]

4.8 Summary

In order to compare the different solutions, they are placed on the two-dimensional axis of the research framework presented in Section 3.2.2. The sensing part of this framework is interpreted as low having only head tracking, medium having head- and hand tracking, and advanced tracking if going beyond medium in some way. They are also compared on whether or not they use real images, and if they have replicated a real area in the form of a model. The solutions are also marked depending on if they are a VFT or not.

Table 4.1: Comparison of Existing Solutions

Solution	**Sensing**	**Taxonomy**	**Replication**	**Images**	**VFT**
Penn State University Application	Low	Basic	No	Yes	Yes
Google Expedition	Low	Plus	No	Yes	Yes
Google Earth VR	Medium	Plus	Yes	No	No
Climate Quest	High	Advanced	Yes	No	No
Player Program	High	Advanced	Yes	No	Yes?
Stanford Ocean Acidification	Medium	Advanced	No	No	Yes
Simulated Nature Walk	Low	Basic	No	Yes (video)	No
Virtual UCF Arboretum	Medium	Plus	Yes	No	Yes
Oppdal VR	High	Advanced	Yes	Yes	Yes

Chapter 5

Implementation

This section starts by documenting the requirements for the new Oppdal VR. Afterwards, it documents the reconstruction pipeline for creating the ground model, and then the implementation of the mechanics and interaction in the application.

5.1 Requirements

In the Specialisation Project leading up to this master's thesis, functional and non-functional requirements were identified. They have been slightly improved in this master's thesis to be clearer and more specific, and one new non-functional requirement (**nFR6**) have been added.

Table 5.1: Functional Requirements

ID	Description
FR1	The Virtual Field Trip (VFT) shall feature a landscape around Vekveselva reconstructed from LiDAR data.
FR2	The VFT shall use the Virtuix Omni omnidirectional treadmill and the HTC Vive Pro head mounted display.
FR3	The VFT landscape shall have flat areas that the user can walk on.
FR4	The VFT shall have the ability to transition between a virtual landscape and footage from the real area.
FR5	The VFT shall project footage either onto spheres or onto the ground, using shaders.
FR6	The VFT shall contain tasks relevant to the field trip that the player can perform.
FR7	The VFT shall have a menu where the application can be started, restarted and exited.

Table 5.2: non-Functional Requirements

ID	Description
nFR1	The application shall offer at least three of Lazzaro's four fun keys.
nFR2	The application shall have tasks with intuitive interaction.
nFR3	The application shall be engaging.
nFR4	The application shall be fun.
nFR5	The application shall have good performance, keeping the framerate high enough to not be uncomfortable.
nFR6	The application shall be based on open source software and tools.

5.2 Creating the Ground Model

As explained more in detail in the Specialisation Project [1], the topology was recreated from LiDAR scans of the area, publicly available at Kartverket [52]. The complete pipeline for creating a usable model for the ground, without sacrificing too much performance, has many steps. In order to get an overview of the process, as well as details and reasoning, the pipeline is presented as a numbered list in Table 5.3, followed by sections detailing the steps. The numbered list also contains a column showing which software or service is used in each step.

The reconstruction pipeline is based on the Specialisation Project which is again based on the master's thesis by Staurset [53]. The pipeline has been expanded and more thoroughly detailed to provide a better overview of the process.

Table 5.3: Reconstruction Pipeline Steps

Number	Software / Service	Description
1	Kartverket	Acquire point cloud in `.laz` files
2	LasTools	Merge the `.laz` files into one
3	LasTools	Filter out the vegetation from the `.laz` files
4	LasTools	Convert `.laz` file to `.txt` file
5	Meshlab	Recreate normals for the point cloud
6	Meshlab	Recreate surface
7	Meshlab	Simplify and cleaning
8	Meshlab	Export model as `.ply` file
9	Blender	Cut model into smaller parts
10	Blender	Texture models
11	Blender	Set origin
12	Blender	Export models as `.fbx` files

5.2.1 Acquire Point Cloud from Kartverket

The first step of creating the ground model is to acquire the LiDAR scans of the area. The scans are openly available at the Norwegian Mapping Authority - Kartverket. On their web pages, the area in question can be marked and the data files will be made available at a custom link address. Depending on the size of the area, the data will typically be divided into several `.laz` files.

It could also be possible to get terrain models directly from Kartverket. One would then have to find software to open the model files (`geoTiff`) and find another way to filter out the vegetation.

5.2.2 Filter with LasTools

LasTools[54] is a semi-open source software developed by Rapidlasso. It has several functions to work on point cloud data, where some are completely open source, and others are free to use for non-commercial projects.

With the `.laz` files available, the most practical thing is to merge the files into one. Afterwards, the terrain can be filtered from the vegetation using one of the only-for-non-commercial functions: `lasground_new.exe`. Finally, the point cloud can be exported as a `.txt` file that Meshlab can read.

5.2.3 Simplify and Reconstruct Surface with Meshlab

The software used for the surface recreation is Meshlab [55]. The software is open source and made for working with large point clouds and models, as well as supporting mesh reconstruction. In order to reduce the complexity of the ground model, the point cloud was sub-sampled outside of the important area. It was sub-sampled to be about 1 point per 1 model unit in Meshlab.

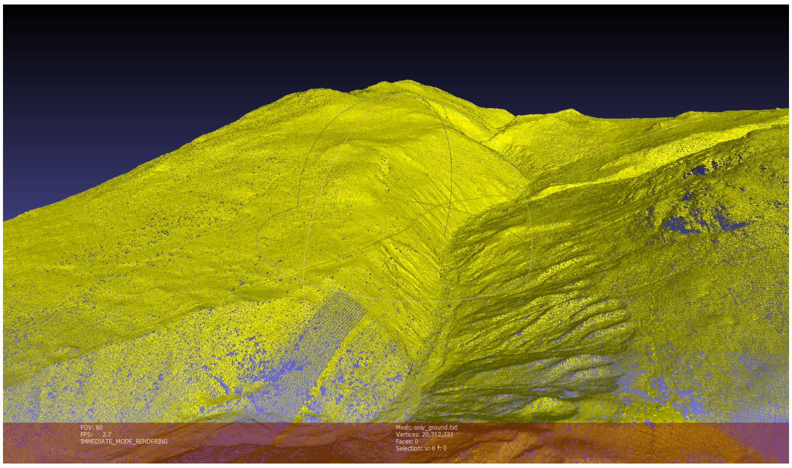


Figure 5.1: Filtered Point Cloud for the Ground in the Vekveselva River Area

Screened Poisson Surface Reconstruction [56] was used to recreate the ground model from the point cloud. It relies on the points having normals, so these normals had to be calculated first. The reconstructing algorithm was tested with different reconstructing depths where the choice landed on 12. This resulted in longer computing time but a good reconstruction quality. The model was also cleaned for duplicate edges and vertices without normals. Afterwards it was exported as `.ply` file.

5.2.4 Cut the Model in Blender

Blender [57] is a versatile, open source software with many different features. It was used to further rework and texture the model where Meshlab proved less appropriate. It was first used to partition the model into three areas to be used for different purposes. This partitioning can be seen in Figure 5.2. This partitioning allows for reworking the area the player will walk on and also to switch out the model for the Storskredet landslide. It also allows to define a game area for teleporting, and have a water tight mesh collider for areas where other models will be swapped in.

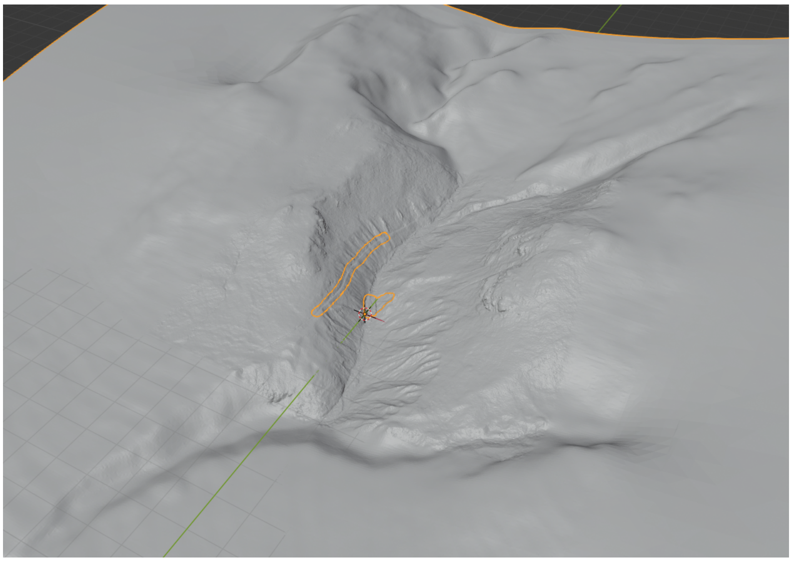


Figure 5.2: Partitioning of the Ground Model After Simplification

5.2.5 Texture Model and Set Origin in Blender

The ground model was textured using a satellite image from Google Maps. The texture ground can be seen in Figure 5.3 below. Afterwards the origin of the model was moved. This needed to be done because the vertex coordinates from the LiDAR point cloud was still preserved in the model, placing the actual topography some 7000 kilometres from the model's origin. The models were offset $[x,y,z] = [-530447, -6945400, -854]$. This offset was applied to all models so they could still be automatically placed relative to one another. The coordinates of the point cloud were in **UTM 32N** with **EPSG 25832**. Finally the ground models were exported as `.fbx` files, as Unity does not support the `.ply` format.

Figure 5.3: Ground Textured with Satellite Imagery

5.3 Implementation in Unity

The Unity game engine was used to create Oppdal VR. This section explores the architecture of the application, which is mostly governed by how Unity is used. Details are then provided on the different components that were made for this VFT.

5.3.1 Overall Architecture

The main building blocks of Unity are *scenes*. These are individual hierarchies of *transforms*, where the transforms in turn have different *components* attached to them. All the objects in a scene are therefore transforms with components, structured in the scene graph hierarchy. The scene graph and components can be seen in Figure 5.4 below. The highlighted ”Walkway11” transform has components like ”Image Viewer” and ”Object Spawner” attatched to it.

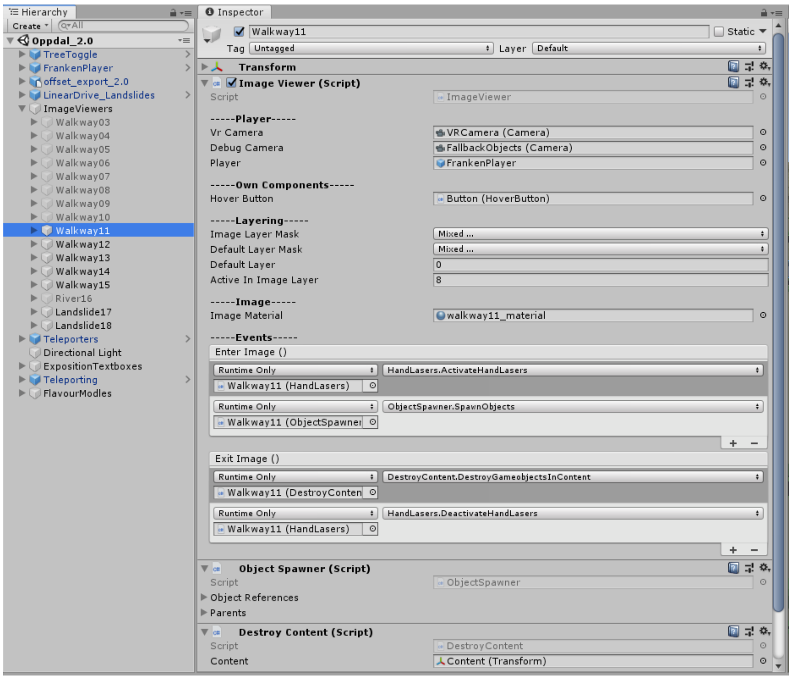


Figure 5.4: Left: Hierarchical Scene Graph, Right: Components Attached to the Selected Transform

Because of the way Unity is structured, it is highly recommended to use **component-oriented** code. This means that code features are loosely coupled and therefore easier to change and reuse. This can be seen in the image above where the components are stand-alone features that are attached to the transform, instead of being hard-coded. Unity has three main ways of supporting the component-oriented approach:

- **Components**
  As described, components are added to transforms to make up the different objects in the scene graph.
- **Linking**
  Transforms, and their components, can be linked to components. This can be seen in the Image Viewer component in Figure 5.4 were transforms like VR Camera have been linked. The transforms can also be searched by name or type in scripts.
- **Events**
  Functions without input parameters or return values can be linked and triggered by events, as seen in Figure 5.4 in the Image Viewer component. This component has two events: "Enter Image" and "Exit Image". Functions can then subscribe to these events, acting as listeners. This allows for components to be loosely coupled to each other without the need for hard-coding their interactions.

The main connections between the different components can be seen below in Figure 5.5. These connections form the main gameplay mechanics of the application.

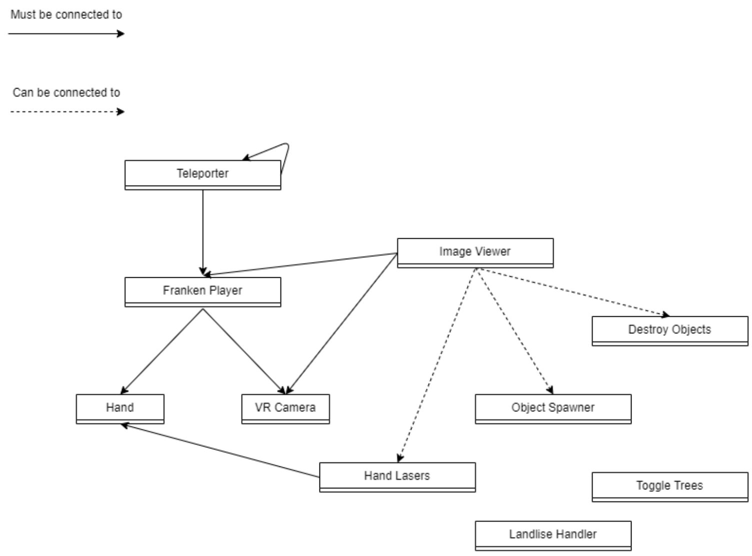


Figure 5.5: Component Interaction Diagram

The interaction can be divided into five main areas:

- **The Player**
  This is the object necessary for movement, looking around with the VR camera and viewing and using the hands. This is the largest and most complicated object, but has been simplified as it has many internal workings.
- **The teleport**
  The teleporter is very simple object in the application, but requires linking to the player to be able to move it.
- **The Hand Lasers**
  This component needs to be linked to the hands of the player in order to activate and deactivate the laser pointer objects native to the hands. It also activates and deactivates logic that allows the pointers to activate other objects.
- **The Image Viewer**
  These are the main gameplay mechanics and have to be linked to the player and camera in order to set the culling mask and change the view for the player. It also sets of events when entering and exiting image mode, allowing game world modifiers to be attached if wanted.
- **Game World Modifiers**
  These are simple objects that manipulate the game world itself without the need for integration with the other main objects. They create, destroy, ac-

tivate and deactivate parts of the game world.

5.3.2 The Player

The player object was created by combining two existing player prefabs from Steam VR and the Omni SDK. The player from Omni SDK is focused on using the Virtuix Omni omnidirectional treadmill as movement input, whereas the Steam VR player has a lot of built-in support for the hand controllers, but is meant to be standing still. The new player was created by adding the Steam VR player as a child in the Omni player and deleting the original VR camera in the Omni player, as there is already one present in the Steam VR player. It can be compared to simply placing the Steam VR player ”on wheels”. This resulted in a player controlled by the Virtuix Omni, but with all the support and integration of the Steam VR player, like adding teleportation as an alternative mode of transportation if the treadmill is unavailable.

5.3.3 Viewing Stereoscopic 360 Images

In order to view the stereoscopic 360 images, the tutorial of Heavers [58] was followed. This solution uses a custom shader to project the images to the skybox of the game world. This method can be used by loading a new empty scene with the custom skybox or change the skybox of the main world. The latter way was chosen in an effort to reduce load time when activating the image mode. When activating the image mode, the rest of the game world is hidden from the player, and the skybox material is changed to the appropriate image.

To control what was to be masked and what was to be shown in the image mode, layers and culling masks were used. The culling mask is a feature in Unity cameras that determines which layers are visible and not. The objects that should be visible were assigned the ”ActiveInImage” layer. This meant that some objects, like the buttons for toggling image mode, had to be assigned layers at runtime. This also required some changes in Steam VR resources as it had not implemented layers as a part of e.g. spawning hand models or using laser pointers. The activation button can be seen under in Figure 5.6.

Figure 5.6: Button for Toggling Image Mode

5.3.4 Point-and-Click Tasks

In order to engage the players, point-and-click tasks were created. These tasks were activated while in ”image mode”. As the tasks are component based, they could also be used outside of the image mode. That could however lead to problems, as the player points at an invisible object that must be placed in the correct place. The tasks were made from textboxes, Steam VR laser pointers and simple plane objects. The textboxes instructed the player on what to point at. The laser pointers visualised the pointing and activated components on the planes. The planes were placed to cover the area of the image that should be pointed at and was then turned invisible. The planes were shown with a highlighter around its edge after it was activated by the user. The Steam VR laser pointers required some reworking to be able to see through other invisible objects. When reworking components, a new component was created that inherited from the original component and overrode where necessary. This was done to keep the original components in case of e.g. updates, which would then be inherited to the custom components.

Figure 5.7: Player Pointing

Figure 5.8: Player Clicked

5.3.5 Different Landslide Models

A tradition of the actual field course it to scan one of the landslides in the area with LiDAR every year. These scans have been used in software to analyse the development of the landslide. Because of this there were several point clouds of the landslide available to be reconstructed and included in the application. They were reconstructed in the same way as the ground model in Section 5.2, having the same offset to be placed automatically. The landslides could then be toggled by setting their active status to true or false.

The interface for selecting the landslide models was a linear drive with a shaft and table from Steam VR. The input of the linear drive was then used to activate the landslides, depending on its position. The interface can be seen below in Figure 5.9:

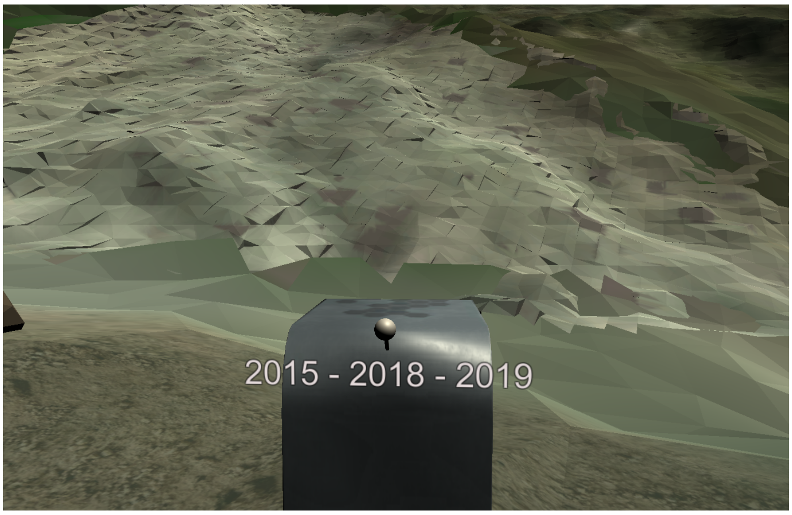


Figure 5.9: The Interface for Choosing Landslide Models

5.3.6 Teleporter

In order to decrease the amount of cosmetic decoration that had to be done, and to keep the player's interest, the game area was reduced from the whole valley to a part where everything interesting was. This meant that the player had to travel down a steep 20m high valley side. This would not be ideal for either of the movement options. It was solved by adding a teleporter that sets the position and rotation of the player to the target teleport station. For simplicity, it reuses the button from the image viewers, but use a different colour to signal the same usage, but different effect. The teleporter is shown in Figure 5.10 below:

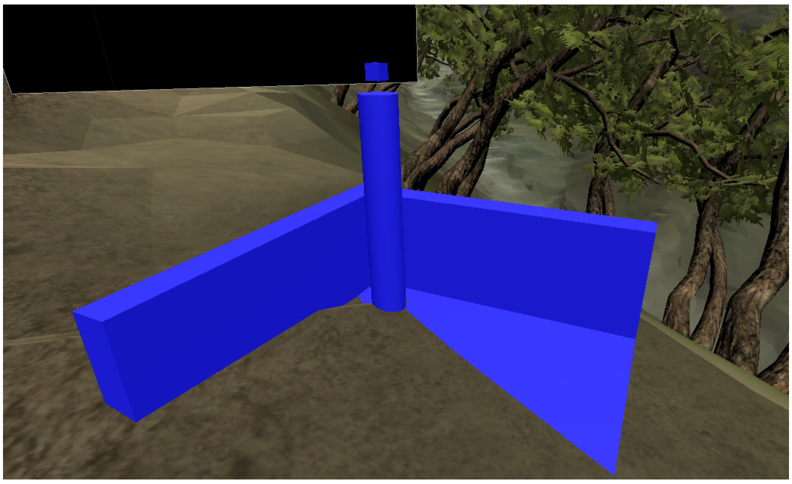


Figure 5.10: The Teleporter for Moving the Player

5.3.7 Toggling Trees

A feature discovered in early prototype testing was the ability to toggle the trees on and off. The trees were added as an aesthetic, but the shape of the valley itself can be of interest in geography. A button was introduced that sets the parent of the trees, and therefore all the children, to active or inactive. Like the teleporter, it reuses the button from the image viewer, but with a different colour, as shown below in Figure 5.11.

Figure 5.11: Button for Toggling the Tree Models

5.3.8 Decorating the Game World

In order to make the application more engaging and lifelike, models of trees, grass and stones were added to some areas where they appear in real life. Additionally, as the satellite photograph used to texture the area only looks good at a distance, the main game area was re-textured. The tool for both of these aesthetic changes was Polybrush [59]. It is a tool for Unity available for free, and is used to paint with textures and place models on the surface of other models.

5.3.9 Preload Scene

One of the ways Unity works is that when a new scene is loaded, all objects are lost unless they are modified with ”don’t destroy on load”. Oppdal VR starts a ”preload” scene that only contains one object, which is not destroyed on load. The preload scene then loads the first ”real” scene. This creates a persistent object that is present in all scenes at runtime, which allows information to be carried between the scenes. This is currently only used for the starting choice of using the Omni treadmill or teleportation to move, but can be expanded to include e.g. a game score.

Chapter 6

Results

The project data was collected in three different ways. First, a simple questionnaire was given to users during the prototype testing. After development of Oppdal VR was complete, a more thorough questionnaire was distributed. This was the main quantitative data source. Because of the Covid 19 lockdown, regular user testing was not possible. Instead, the main questionnaire was accompanied by a video playthrough of the application. While this was in circulation, interviews with domain experts were conducted.

6.1 Prototyping Questionnaire

During the prototyping, Oppdal VR and the Penn State application were tested by a total of 11 people. As this was focused on testing the applications, not gathering data, only two of these answers are related to Oppdal VR. All the participants were geography students, and 8 of the 11 students had attended the AFT and been to the area in real life. The prototype testing was done on the latest version of the Penn State application and on the unfinished Oppdal VR. Because of the non-standardized question format and uneven distribution of responders on the applications, the questionnaire is not fully analysed for differences between the two. Generally, they both scored well on the user experience questions. A comparison between self-assessed learning outcome is presented below in Figure 6.1:

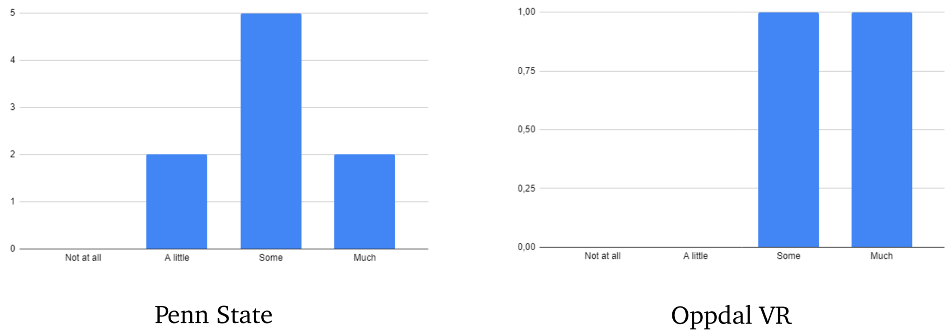


Figure 6.1: Learning Outcome for the Penn State Application and Oppdal VR

6.2 Main Questionnaire

The main questionnaire result graphs are included in their entirety in Appendix D. The key takeaways and most relevant graphs are presented in the following section. This questionnaire was distributed with the video playthrough of Oppdal VR. The questionnaire only asks about that application, not the Penn State application.

Demographic Representation

Of the 32 responders, the vast majority (94%) were in the age group 21 - 35. There were 53% students and 44% employees as the two largest groups. Of the responders, 74% agreed to enjoy video games, but only 19% had much experience with VR. Their experience can be viewed in Figure 6.2 below:

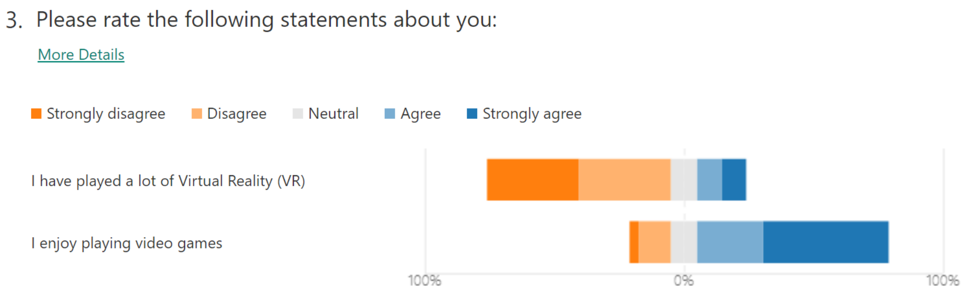


Figure 6.2: Questionnaire Results - Responder Experience

Application Quality

38% of the responders studied, or had a background in geography. Half of these had been to the real Vekveselva area. When it comes to realism, the 360° images scored good, whereas the 3d models scored poorer. When asked about the in-game tasks, they were ranked as not resembling the real tasks in the AFT. The realism answers are present below in Figure 6.3:

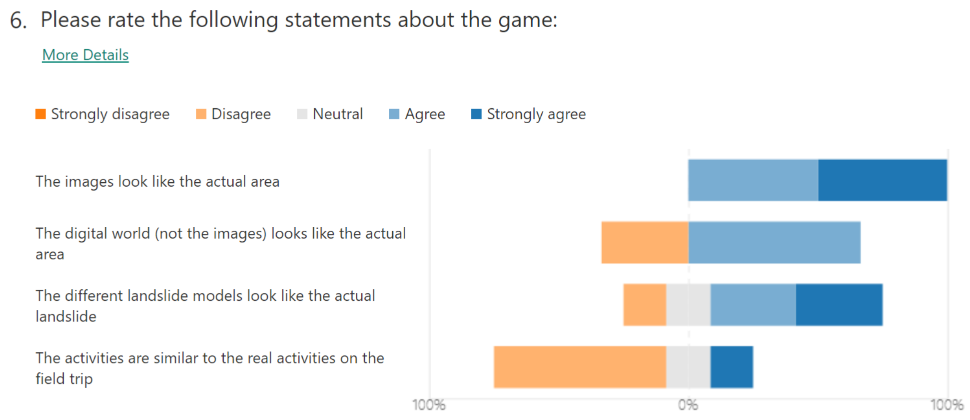


Figure 6.3: Questionnaire Results - VFT Realism

At least half of the responders who had visited the real area agreed to the app improving their ability to identify different land forms, as seen in Figure 6.4 below:

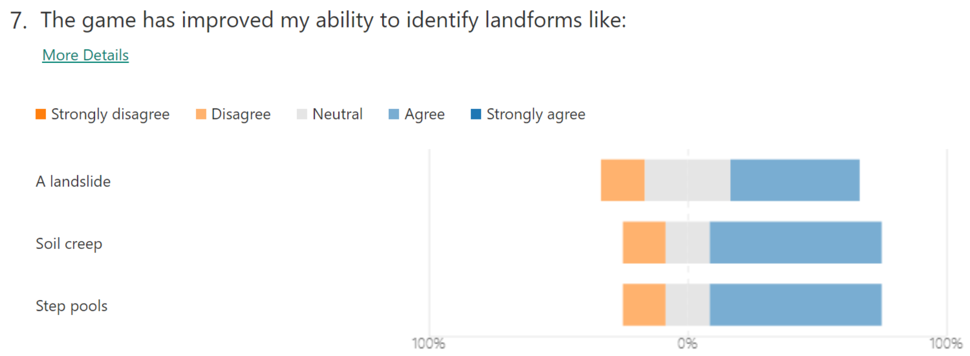


Figure 6.4: Questionnaire Results - VFT and Observation Skills

The System Usability Scale (SUS) was used to find an average usability score of 81, with the lowest of 62.5 and the highest of 90. The SUS questions were only given to those who tested Oppdal VR, of which there were five.

Opinions of the Game and VFTs

Overall a majority of at least 67% of responders agreed to Oppdal VR being an active learning process, giving the user control and engaging them. The answers are shown in Figure 6.5:

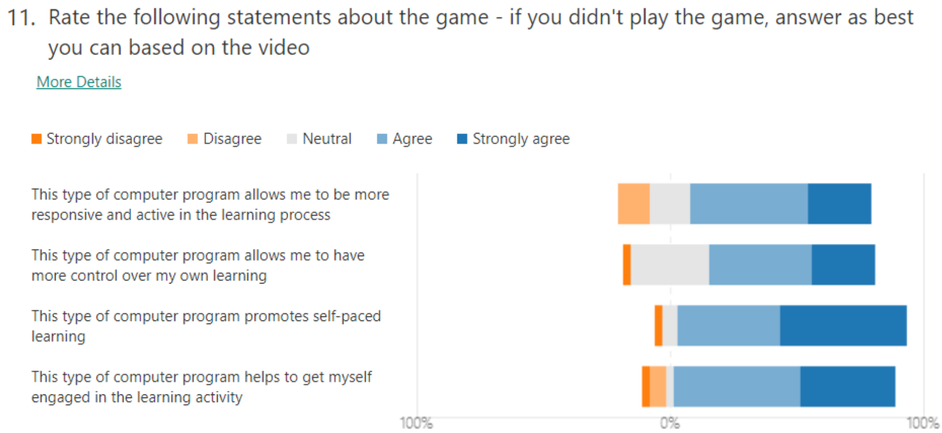


Figure 6.5: Questionnaire Results - VFTs and the Learning Process

When it comes to the perceived learning effectiveness, the responses are generally positive. The majority of answers are on the ”agree” side of the spectrum, although there is a significant amount of ”neutral” answers, sometimes as high as 34 %. The questionnaire results on motivation and learning outcomes are shown in Figure 6.6 below:

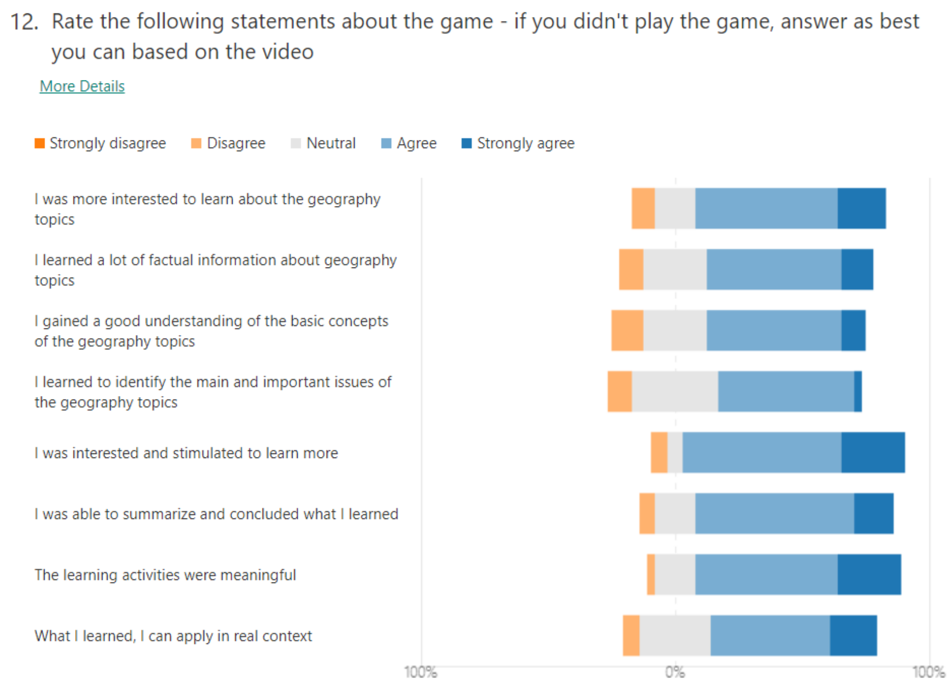


Figure 6.6: Questionnaire Results - Motivation and Learning Outcome

As the questionnaire asked whether or not the responders had geography background, it is possible to divide the data into the target audience (geography background) and the general public. This has been done for the second question from Figure 6.6, as it directly asks learning outcome. The answers can be viewed in Figure 6.7 below, where the target audience is on the left and the general public on the right. Due to the number of participants it can be hard to draw absolute conclusions, but 70% of the general public answered ”Agree” or higher. Of the target audience, 50% answered ”Agree”, 33% were neutral and 17% disagreed.

Target Audience General Public

Figure 6.7: Learning Outcome for Target Audience and the General Public

When it comes to opinions about VFTs, the answers are more nuanced. In general, the VFT was rated positively, but when compared with an AFT 72% would rather attend the AFT than the VFT. 50% also disagreed with VFTs being able to replace AFTs. However, 41% that agreed they could. 100% agreed that both VFTs and AFTs can be useful when learning geoscience materials. The answers are shown below in Figure 6.8:

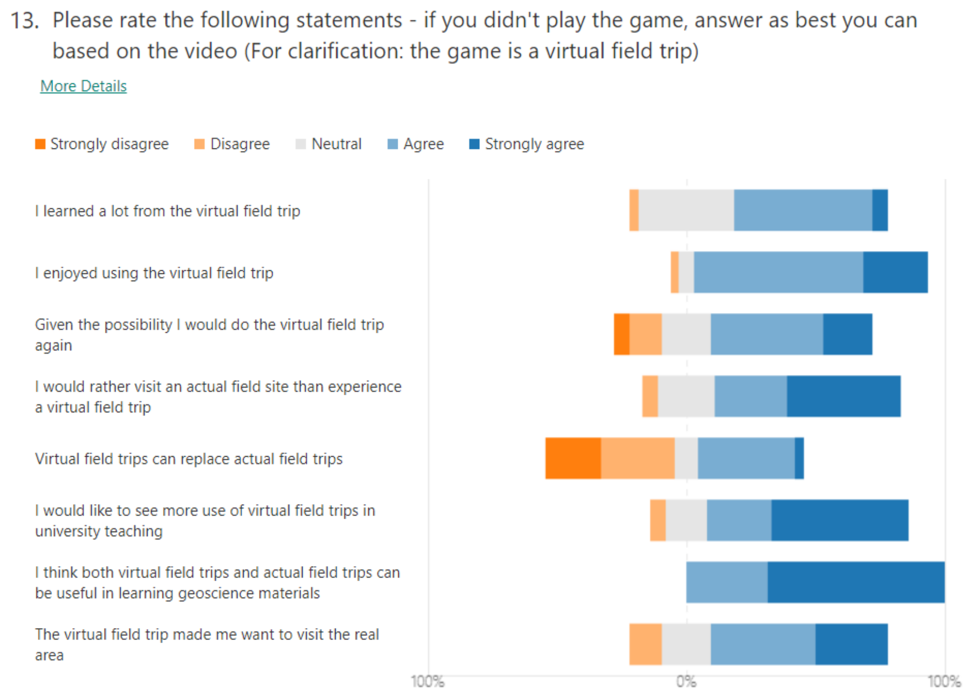


Figure 6.8: Questionnaire Results - Opinions About VFTs

The user experience of Oppdal VR was overall rated as good. The largest area for improvement appears to be excitement, with 23% disagreement and 50% agreement to the VFT being exciting. The answers are shown below in Figure 6.9:

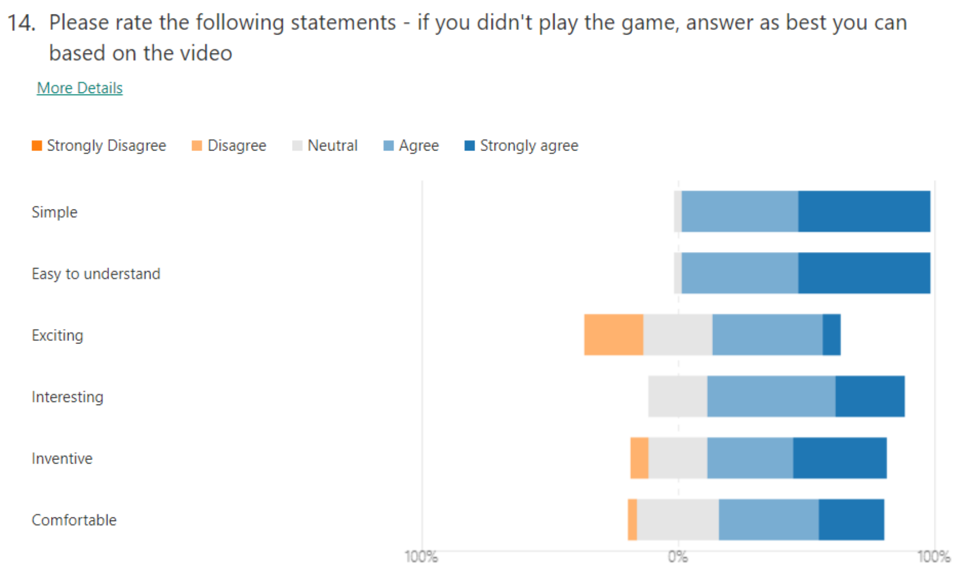


Figure 6.9: Questionnaire Results - User Experience

The last question in Figure 6.9, '*The application is comfortable*", is shown below in Figure 6.10 where only those who tested the application are included. 40% were neutral, 40% agreed and 20% strongly agreed.

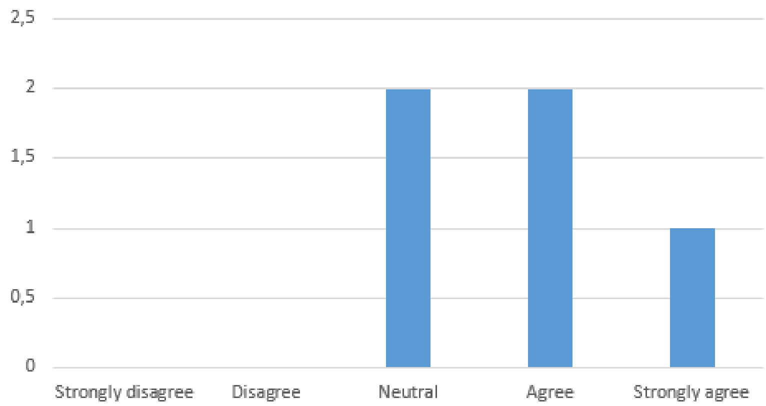


Figure 6.10: Tester's Rating of Oppdal VR Being Comfortable

6.3 Interviews

As stated in Section 2.2.2, there were 7 informants with backgrounds in geography, creation of VFTs and immersive learning tools. They were interviewed about Oppdal VR and VFTs in general.

The overall feedback for Oppdal VR were positive, with many suggestions for improvements. In general, the response was positive to VFTs and their use as a learning tool. The answers are grouped together by themes, looking at Oppdal VR first and its different features, before going into VFTs and their usage. In the case of the informants giving conflicting statements with each other, they are explicitly commented as conflicting. The different statements do not necessarily mean the informants wholeheartedly disagree, as they were interviewed one by one without being able to discuss between themselves.

All of the interview statements can be viewed in Appendix B where they are presented as individual list entries. This can be used in the event of expanding on Oppdal VR at a later time. The following are the most important parts of the answers.

Application Feedback

As Oppdal VR is supposed to be a stand-alone application, two of the informants pointed out the lack of a proper introduction to give context to the learning and experience. From a pedagogic stand, three of the informants also noted that the lack of audio could be improved. Using voice recordings or a virtual character to explain the concepts was proposed, and this would also remove the need for many of the textboxes. The textboxes themselves were rated to be some degree of intrusive by four of the informants, and was described by one as "*having commercial bill-boards in the nature*". It was suggested by one of the informants to use video footage instead of still images. They explained that showing video of students in the field could better prepare new students for the tasks they have in the field.

The resolution of the 3D models was pointed out by four of the informants to be on the scarce side. This was both for the ground model, as well as the landslide models. Two of the informants also expressed a wish for having more educational content in Oppdal VR. Several of the informants also proposed to add more game elements, like scoring for completing tasks.

Although the grounds for improvement have been highlighted, the general response to Oppdal VR was positive. The combination of 360° images and the reconstructed landslide was commented by most as working really well and being a somewhat new feature. The interactivity of the pointing tasks was also appreciated, as it was said to make the VFT more engaging and activating. The ability to remove the trees was described as adding a perspective that is not present in the

AFT, as well as relating to geography practice where this is done using other software. The ability to see the landslide scans from different years was also positively received for adding a historical perspective to the VFT.

Opinions on Virtual Field Trips

During the interview part about VFTs in general, the informants gave their opinions on VFTs and their use, as well as providing some observations and pedagogic concepts.

The Use of VFTs

On the use of VFTs, most informants stated the repeatability and accessibility to be one of their core strengths. This, coupled with repetition having a large role in pedagogy, was said to make the VFTs good learning tools. It was also pointed out by some of the informants that VFTs have the ability to go beyond replication and add content not originally in the AFT. The VFTs were also pointed out as being active learning, which is thought to enhance the learning outcome.

The Use of AFTs

When it comes to the use of the AFTs the informants gave both positives and negatives. On one hand AFTs give very good and realistic experience. On the other hand, they are costly and dependent on a lot of factors, like the weather. Students also uses a lot of time in the field to get their bearings according to two of the informants. There are also problems with scalability, as the more students there are, the harder it is to listen to instructors giving important information. Several of the informants also pointed to the social aspects being a very important part of the AFTs. There were some conflicting statements when asked what the most important part of a field course is: the preparation, the trip or the afterwork. Between the answers, the trip and the preparations were mostly discussed, but given a relationship where the one is dependent on the other.

Motivation and Engagement

When it comes to motivation and engagement, the VFTs were regarded by all as more motivating than conventional mediums. One informant noted however that this may be because it differs pedagogically, and not because the medium is necessarily better in itself. There was some uncertainty on whether or not the students lack motivation, as it can differ greatly within the group taking the course. The consensus was that there is always someone who will benefit from more motivation, and VFTs can additionally increase the learning outcome.

Replacing AFTs with VFTs

There were divided opinions on whether or not VFTs can replace AFTs. Generally, the geography informants were not convinced, as there is something special with AFTs that is hard to replicate correctly. The non-geography informants were more positive, pointing to the Penn State paper showing better learning outcome in the VFT than in the AFT. One of the geography informants also pointed out that VFTs already had replaced AFTs because of the Covid 19 lockdown. The informants agreed that using a VFT together with an AFT could improve the learning outcome of field courses.

Automation of VFTs

All the informants agreed on the automation of VFTs increasing their use and being a good idea. As pointed out by one the Penn State informants "*There is a knowledge gap between creating the VFTs themselves and creating the content that should be bridged*". This informant also pointed out that there are many steps, especially in the beginning of creating a VFT that are similar.

Chapter 7

Discussion

7.1 The Process of Creating a Virtual Field Trip

Recreating the topology from LiDAR scans, instead of creating it manually, ended up quite successful. After the reconstruction pipeline was documented, it was easily used to create the models needed, both for the ground and the landslides. It has the possibility of being an accurate representation of the real world because it is based on real world measurement. However, it was hard to pin down the optimal resolution of the models, especially for the ground model. Using unfiltered LiDAR data yielded a very large model that crashed the modelling software Blender. The vertex count needed to be reduced, but reducing the vertex count too much would result in an inaccurate model. The solution to divide the ground area into the main play area and the scenery worked fairly well. It managed to save performance where possible and provide more detail for the main area. From the interviews however, it seems that the vertex count was too low. Although it is better than overshooting the vertex count and creating performance loss, it leaves room for improvement and fine-tuning.

Texturing the ground model was the least automated step in the reconstruction pipeline. This was done manually in Blender and required sufficient knowledge of the modelling software. There are possibilities of using Meshlab for auto-aligning and texturing models, but this approach was not fully explored. Using the satellite images for texturing also lead to a very coarse result. This was mended by painting additional textures over the main play area to improve the quality. This in turn means more manual work and time invested, as well as opening up more room for incorrectly replicating the real area.

Keeping the original coordinates of the 3D models, albeit with an offset, was a huge help in the creation of Oppdal VR. This allowed the images and different landslide models to be automatically aligned in the landscape, reducing work and increasing the accuracy of the reconstruction. The vegetation was however not automated, and had to be placed manually. There are signs that this can be automated, as LasTools is able to filter the ground from vegetation. This means that the data classified as vegetation could be used to automatically place e.g. randomized tree models in those areas, further reducing the need for manual work. There does not appear to be any existing solutions for this.

The data collection shows a wish for more VFTs in education. From the interviews and the literature there also seems to be a gap between domain experts and the know-how to create VFTs. Bridging this gap could lead to more VFTs and better learning outcome for students. Although there are some applications already in the market, like Google Expedition, they mainly rely on 360° images and audio. With LiDAR scans and satellite images available, there is a possibility to automate the creation of more advanced VFTs using world models. The use of a virtual world to move around in can also open up the VFTs for more interaction, making them more active and engaging.

7.2 The Role of virtual field trips in Education

The data collection shows an overall positive attitude towards VFTs and to use them as learning tools. As found in the interviews, this attitude seems to come from the VFTs being more active and engaging than e.g. lectures, and therefore being more motivating. The interviews also highlighted several drawbacks with AFTs that are not present in VFTs, like the challenge of hearing information from a teacher when in the field. This can explain why VFTs had better learning outcome than AFTs in Penn State's research project.

Although the overall realism of Oppdal VR was rated as fairly good, the current tasks were not regarded as resembling the tasks of the AFT. As accurately replicating the AFT is an important part of a VFT, this would be important to improve. The interviews also implied that students are often under-prepared for AFTs. This could be improved by the VFT tasks being more life-like. It could also be improved by following the suggestion of showing video footage of students in the field. One of the strengths of VFTs, as stated both by literature and the interviews, is to expand on the AFT by including functionality and content not originally present. This was pointed out as one of the most important strengths of VFTs during the interviews. It gives the ability of having the theory present in the virtual field where it is applicable, in order to show the theory in practise. This is not the case for AFTs and might explain why VFTs can increase the learning outcome.

One of the more controversial questions about VFTs is whether or not they can replace the AFTs. The questionnaire data points towards this not being the case, as many of the interviews also did. The main opposition towards this is because reality cannot be replicated perfectly, as well as the importance of practical learning in a real environment. The main arguments for replacement were the accessibility, learning outcome and additional content to an AFT. It was also pointed out that many AFTs were already replaced by VFTs during the Covid 19 lockdown. One of the differences that arose from the interviews was the importance of the social element in an AFT, which can be hard to reproduce in a VFT. There was however a unison agreement, both in the interviews and the questionnaire, that that using VFT together with an AFT could increase the quality of the learning. This would also overcome the cons of both mediums, as the VFT could provide the information, training and learning, while the AFT gives the opportunity for working with the real world in a social setting. From the interviews, it would appear that the best use of the VFT would be as preparation for the AFT, but it could also be used to re-live the experience.

The main questionnaire data could be separated into the target audience and the general public. This has not been done for the majority of the results because of the sample size, as there was only 12 with geography background. The exception is the rating of the statement "*I learned a lot of factual information about geography topics*, that explicitly asks for self-assessed learning outcome. The data points towards the learning outcome being larger at the general public. This can be interpreted as the content of the VFT not being too advanced for the general public, and the VFTs therefore being viable for a broader audience than just the geography students. Whether or not this holds for a fully completed VFT is difficult to answer.

7.3 Implementation of Requirements

Not all of the the requirements, stated at the beginning of the project, ended up being implemented. The reason for this is that the project was governed by the minimal viable product (MVP) methodology. This was done with a prioritized list of features that was continuously discussed with the geography department / product owners.

FR1 - *using LiDAR to create the virtual landscape* was successfully implemented. **FR2** - *using the Virtuix Omni and HTC Vive Pro* was not completely implemented. Due to lack of access to the omnidirectional treadmill during the Covid 19 lockdown, and the introduction of an alternative way of movement, the treadmill input turned out to be non-functional. On the other hand, Oppdal VR was able to run on all Steam VR headsets, not only the HTC Vive. **FR3** - *having flat areas for the player* turned out to be automatically implemented because of changes. The requirement was added because the original play area needed artificial rework to be traversed with the omnidirectional treadmill. It was decided to reduce the play area to compact the game experience, and with that the uneven parts of the ground model were no longer included.

FR4 - *transitions between 360° images and the reconstructed landscape*, was fully implemented. **FR5** - *projecting images onto the ground around the image transition areas using shaders* was not implemented. This was prioritized down in the MVP methodology in favour for other functionality. **FR6** - *having tasks relevant to the field trip* was partially implemented. Steps were taken to create observational tasks to resemble activities on an AFT. However, as found in the questionnaires, it was not entirely successful and was rated poorest on resemblance. **FR7** - *having an in-game menu* was also prioritized down in favour of other functionality. This is partly taken care of with Steam VR's own in-game menu that can pause and exit the game.

nFR1 - *having at least three of Lazzaro's four fun keys*. This requirement is hard to assess as there is no absolute way to know if a fun type is present or not. As the application is a VFT, the Serious Fun is already present because it creates value outside of the game itself. There are currently no multiplayer or non-player characters present, so the People Fun is absent. One can argue that walking around and exploring the images leads to curiosity and the Easy Fun. The last type, Hard Fun, is about whether or not there is a challenge present. There is some in the pointing tasks, although they are not mandatory for progressing in the game. Even though the Hard Fun is present, it is not very prominent. This could be mended by adding more challenging tasks, as well as incorporating e.g. a score to give more incentive to perform the tasks.

nFR2 - *intuitive interaction* was fairly well implemented. The different functionalities were created with this in mind by reusing the button interface as much as possible. This was to not introduce the player to too many concepts. The responders to the questionnaires also seemed to agree on the application being intuitive, but this can be affected by changing the interface in the future. In the interviews it was suggested to move interaction from in-game buttons to the controllers. This is a less intrusive way to include it, but will require more tutorials and can make the application less intuitive. **nFR3** and **nFR4** - *being engaging and fun*, was fairly good implemented. From the questionnaire data it scored well on engagement and motivation.

nFR5 - *having good performance and framerate* was upheld in the final prototype. The application was rated as agreeing or neutral to being comfortable, by users who actually tested it. When running, the framerate did not dip under 90, although this was only observed and not recorded.

nFR6 - *basing the prototype on open source* was implemented. All tools and software were open source, with the exception of the vegetation filter in LasTools. This was however open sourced for non-commercial use, so it works for the purpose of this application.

Chapter 8

Conclusions and Future Work

This section concludes the master's project by answering the research questions from Section 1.5. Next, the contributions this project has to the field of VFTs are listed. Lastly, the future work of both the project and Oppdal VR are proposed.

8.1 Conclusion

RQ1 - *How can a VFT be developed?*
The reconstruction pipeline documented in Section 5.2 works well for recreating the environment for a VFT. The process also shows clear possibilities for automation, with the vertex count, texturing and vegetation placement being the current challenges. The process also relies on open source software, given that the application is non-commercial. The addition of images and 3D models is easily done when everything keeps their relative coordinates.

RQ2 - *What game design theories apply and should be used in a VFT application?*
The game design was mainly based on Lazzaro and the recommendation of implementing at least 3 of the 4 fun keys. This was done to some extent with the weakest fun key being Hard Fun because of time constraints. Oppdal VR was still rated in the main questionnaire as engaging, which can deem the fun keys as appropriate game design for VFTs. The main questionnaire does however only have 5 testers of the VFT, so the conclusion can not be certain.

RQ3 - *Can VFTs be valuable support tools for courses with field trips?*
Both the interviews and the main questionnaire points to VFTs being a wanted and a valuable addition to the course GEOG2012 at NTNU. It was however discovered that most students and professors are reluctant to replacing AFTs with VFTs, although it is better than no field trip. The consensus is on using VFTs as preparation to AFTs, to get the positive aspects of both.

RQ4 - *Can the use of interactive elements in a VFT lead to a better learning outcome than passive applications based on displaying images?*
Because of changes made to the project to accommodate the Covid 19 lockdown, Oppdal VR and the Penn State application were not compared outside of the prototyping phase. With only two people testing Oppdal VR at the time, no conclusion can be made. The data is however similar, so one can argument that they have a similar learning outcome.

RQ5 - *Can VFTs have educational value for the general public outside of their academic discipline?*
As the majority of responders to the main questionnaire were non-geography students, it gave some insight into the learning outcome for that demography. The answers point to the learning outcome being as good, if not better, than for the geography students. For the VFT prototype in question, it seems to have value for people outside of the geography discipline.

8.2 Contributions

The following are the main contributions to the field of VFTs from this project:

- **The reconstruction pipeline** for models from LiDAR scans and satellite images have been further documented to ease the creation of VFTs and facilitate more automated creation. The need for this automation as well as the lack of current solutions has also been identified.

- **Data on the use of VFTs and their effectiveness** has been collected from students and domain experts on geography and VFT creation. This data points towards VFTs being valuable additions to courses with AFTs and to them being wanted by both the students and professors. The data also shows that the VFTs have the possibility to teach not only the target audience, but the general public.

- **Relevant game design theory to use in VFTs** has been identified. Although it was not sufficiently tested, the data can point towards the theory being beneficial for the engagement in the VFT.

8.3 Future Work

As with all projects, not everything was possible to complete or investigate. The following are identified leads that could be investigated more.

Project

- Investigate automatic landscape recreation and create a prototype that can be used to make virtual game worlds.
- Perform user testing with target audience, as this was not possible because of the Covid 19 lockdown.
- Compare Oppdal VR to the Penn State application when conducting user testing.
- Interview geography students, not only domain experts, to get the other perspective of the use of AFTs, VFTs and Oppdal VR.
- Improve the gameplay elements of Oppdal VR to better investigate their effect on the engagement and learning outcome in VFTs.

Application

- Determine a more satisfying vertex count for the 3D models that are used.
- Create a better introduction to make Oppdal VR work better as a standalone application.
- Introduce more gameplay elements, like score for completing tasks or making tasks mandatory.
- Improve pointing task area and feedback to make them more engaging.
- Get domain experts in geography to create the learning content of the application to improve its quality.
- Create a more interactive tutorial for the pointing tasks to make sure it is understood by the user.
- Improve the audio design of the application and move the learning content from the textboxes to voice recordings to improve engagement and learning outcome, as well as removing obstructions in the terrain.
- Investigate the use of controller input instead of in-game buttons to decrease the use of intrusive game objects. Pair this with tutorials for the different functionalities as well as markers for where they can be used (if they are position sensitive, like the images).
- Decorate the application with more vegetation (or automate this process) to better replicate the actual area and enhance the feature of deactivating the vegetation.
- Improve the placement of textboxes to increase readability and consistency.
- Refrain from having textboxes active by default, make them appear when hovering over or activating certain items.
- Create an installer to make it less effort to download and test the application for users.

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Appendix A

Semi-Structured Interview

The interview is divided into three parts. The first two parts were asked to the majority of the interview subjects. An interview was however performed after a domain expert had tested the application together with the Virtuix Omni omnidirectional treadmill. This interview used the first and last part of the interview questions.

Application

1. What are your first thoughts after seeing the game/application?
2. What did you learn from the experience?
3. What do you think of the image "modes"?
4. What do you think of the textboxes throughout the application?
5. What do you think of the pointing tasks?
6. What do you think of the tree toggling functionality?
7. What do you think of the functionality for different landslide models?

VFT

1. What do you think about Virtual Field Trips as a support tool for courses with field trips?
2. How do you think VFTs could best be used in a course? E.g. preparation
3. What do you think about virtual field trips replacing actual field trips?
4. What are your thoughts on visiting the area after a virtual field trip, compared to only experiencing the virtual field trip?
5. What do you think about Virtual Field Trips and those who are unable to attend the Actual Field Trip? (Due to schedules or other impracticalities)
6. What is most important: the field trip or the work before and after?

7. Looking at VFTs as a learning tool, what are your thoughts on the motivation for using them compared to other learning tools?
8. Do you think any extra motivation is needed for students when preparing for a field trip?
9. Do you think Virtual Field Trips are better or worse learning tools than its alternatives (like books and maps)?
10. Would you use Virtual Field Trips more if there was an automated way / an easier way to make them – meaning you could make them/most of them yourself?

Omni Testing

1. How was the VR part of the game? Any "bad tastes" or "don’ts" that are present?
2. Is there any VR functionality that could be included that isn’t?
3. How does the Virtuix Omni affect the application?
4. How life-like does the application feel? How similar is it to walking around a real area?

Appendix B

Interview Answers

Application Feedback

- Several informants expressed a lack of introduction and an overall context for the Oppdal VR.
- There was a want for more educational content to be present.
- More audio could be added to enrich the experience, as well as conveying more information using speech instead of text.
- Diagrams and videos could be included to give more information.
- The digital landscape- and landslide models could have a higher resolution/vertex count.
- Interaction could be done through the controllers instead of the in-world buttons, although it would requires more tutorials.
- A simple measuring device could be added for in-game data collection.
- Multiple choice questions and answers could be added to engage the users.
- More game elements could be added to make the VFT more fun.
- Support for multiplayer could be added to give users a more social experience.
- Video footage of students in the field could be added to show the users how the real work is done.
- The vegetation gives more realistic expectations for the actual area.
- More vegetation could be added to make the digital landscape resemble the real landscape more closely.
- The VFT adds functionality that is not possible on the AFT

Images

- The combination of 360° images and digital landscape works very well.
- The images offers a level of detail that is very hard to replicate with the virtual landscape. Because of this the images should be in the highest res-

olution possible, as some observations are of very small things.

Pointing Task

- The tasks are engaging and activates the user, which is good.
- The correct area of pointing could be better fitted to the actual area.
- The tasks could offer better feedback when completed, incorporating game elements like score or showing a video of the topic.

Textboxes

- The placement and orientation was sometimes not ideal, making them harder to read.
- The textboxes themselves are very intrusive in the landscape and can block the view. "*Like having commercial billboards in nature*"
- Textboxes could be triggered by some interaction instead of always being present.

Different Landslide Models

- It is very interesting to see historic development.
- Functionality for comparing two years of landslides with colour coding could be added, as is already possible in GIS software.
- The landslides could also be compared using 360° images.

Toggling Trees

- It is very good to remove the distractions and get a clear look of the topography.
- This is already done in geoscience, so it is a nice parallel.
- More trees could be added to better show the advantage of removing them.
- The user could be asked to draw the shape of the valley to make it more engaging.

Opinions on Virtual Field Trips

The Use of Virtual Field Trips

- VFTs can be repeated, which is good for learning.
- VFTs can be used as preparation for an AFT.
- VFTs can be used to train observational skills.
- VFTs are active learning tools, which is good.

- VFTs are more accessible than AFTs.
- VFTs can help visualise things like maps, which is hard without a lot of training.
- VFTs can go beyond replicating AFTs and add functionality that is not possible in the field.
- VFTs can familiarize students with the area and make them more effective in the field.
- VFTs might ”kill” the joy of seeing an area for the first time.
- VFTs can be used to experience details that were not observed when in the field.
- VFTs should run on scalable hardware to make them accessible to larger groups of people.

The Use of Actual Field Trips

- Students use a lot of time to get their bearings and familiarize themselves when in the field.
- AFTs are hard to scale, especially if consisting of someone explaining knowledge to the participants.
- AFTs are generally expensive.
- AFTs are not usually repeated.
- AFTs have a lot of variables and uncertainties, like the weather.
- AFTs can be in dangerous locations.
- AFTs have a large social aspect, which can impact motivation and learning.
- The importance of AFTs compared to preparation and post work has conflicting answers. Many argue that they are of equal importance, others that AFT are most important. Some state that AFT together with preparation is most important and that post work is mostly to make the knowledge ”stick”.

Replacing AFT with VFT

- The question of replacement produced conflicting answers. Several stated that AFTs are an important experience it is difficult or even impossible to recreate virtually. Others pointed to research done by Penn State that implies learning outcome can be higher on a VFT [40] compared to an AFT. Someone also pointed out that VFTs have already replaced AFTs during the COVID 19 lock down, as the alternative was to do nothing at all.
- One should prioritize facilitating AFTs before replacing them, especially for those who are unable to join.
- A combination of VFT and AFT can be better than replacing.

Motivation and Engagement

- VFTs are generally regarded as more motivating learning tools than traditional mediums like lectures and books.
- VFTs are more fun.
- VFTs might be more fun because they differ from lectures. Some amount of fun could be added without VFTs by changing the pedagogic techniques of the teaching.
- Whether or not students need more motivation gave conflicting answers. Some stated they do, while others stated they are very motivated for field work. It was also noted that motivation differ a lot within a group of students.
- Students are not very well prepared for AFTs and do not know everything that is expected from them.
- Students are generally less motivated for the after work.
- VFTs can possibly improve the learning outcome of the most motivate students, and help motivating the less motivated students.

Automatic Creation of Virtual Field Trips

- Everyone who were interviewed agreed that automation of VFTs would increase it's their usage.
- The process of creating VFTs has many similar stages, especially early in the process.
- There is a knowledge gap between creating the content and creating the VFTs themselves.
- There are existing tools for creating VFTs, but not very advanced. Like Google Expeditions.
- It should be possible to connect VFTs to GIS software, as GIS already works with landscape models.

Appendix C

Questionnaire

The questionnaire was conducted using Microsoft Forms. It was divided into sections, where only one section was visible at a time. There were also two conditional sections, depending on whether or not the user had been on the actual field trip, and whether the user had tested the game or watched a video demonstration of the game. These questions were marked as mandatory. The conditional branching is indicated with [next section] after the answer alternatives.

Many questions were answered using a five-point Likert scale: strongly disagree - disagree - neutral - agree - strongly agree. This are marked with [**Likert**]. The other questions are single-answer questions.

The questions and information are documented below:

Header

Oppdal VR Virtual Field Trip

Questions about the learning game "Oppdal VR Virtual Field Trip"! You must watch the demo video or play the game before answering.

The questions are voluntary, anonymized and do not collect personal data.

Section 1

By answering you agree to the gathering of anonymized, non-personal data

more information can be found at: https://drive.google.com/open?id=1hRc-EDQiK-DvNYD56oW_7d6OkQT-ntXx

Section 2

First some general questions about you!

What is your age group?

- 0 - 20
- 21 - 35
- 36 - 50
- 50+

What best describes you?

- Student
- Employed
- Other

[**Likert**] Please rate the following statements about you:

- I have player a lot of virtual reality (VR)
- I enjoy playing video games

Do you study geography? (Or do you have a background in geography?)

- Yes
- No

Have you been to Vekveselva in real life (through the NTNU course GEOG2012 - Field Course in Physical Geography)

- Yes [Go to section 3]
- No [Go to section 4]

Section 3

GEOG 2012 - Field Course in Physical Geography

[**Likert**] Please rate the following statements about the game:

- The images look like the real area
- The digital world (not the images) looks like the actual area
- The different landslide models look like the actual landslide
- The activities are similar to the real activities on the field trip

[**Likert**] The game has improved my ability to identify landforms like

- A landslide
- Soil creep
- Step pools

Section 4

Did you play the game in VR or did you watch the video?

- I played the game in VR [Go to section 5]
- I watched the video [Go to section 6]

Section 5

System usability scale

Did you use the omnidirectional treadmill or teleporting to move around?

- Teleporting
- Omnidirectional treadmill

[**Likert**] Please rate the following statements about the game:

- I think that I would like to use this system frequently
- I found the system unnecessarily complex
- I thought the system was easy to use
- I think that I would need the support of a technical person to be able to use this system
- I found the various functions in this system were well integrated
- I thought there was too much inconsistency in this system
- I would imagine that most people would learn to use this system very quickly
- I found the system very cumbersome to use
- I felt very confident using the system
- I needed to learn a lot of things before I could get going with this system

Section 6

Control and active learning

[**Likert**] Rate the following statements about the game - if you didn't play the game, answer as best you can based on the video

- This type of computer program allows me to be more responsive and active in the learning process
- This type of computer program allows me to have more control over my own learning
- This type of computer program promotes self-paced learning
- This type of computer program helps to get myself engaged in the learning activity

Section 7

Perceived Learning Effectiveness

[**Likert**] Rate the following statements about the game - if you didn't play the game, answer as best you can based on the video

- I was more interested to learn about the geography topics
- I learned a lot of factual information about geography topics
- I gained a good understanding of the basic concepts of the geography topics
- I learned to identify the main and important issues of the geography topics
- I was interested and stimulated to learn more
- I was able to summarize and concluded what I learned
- The learning activities were meaningful
- What I learned, I can apply in real context

Section 8

Opinion about virtual field trips

[**Likert**] Please rate the following statements - if you didn't play the game, answer as best you can based on the video

(For clarification: the game is a virtual field trip)

- I learned a lot from the virtual field trip
- I enjoyed using the virtual field trip
- Given the possibility I would do the virtual field trip again
- I would rather visit an actual field site than experience a virtual field trip
- Virtual field trips can replace actual field trips
- I would like to see more use of virtual field trips in university teaching
- I think both virtual field trips and actual field trips can be useful in learning geoscience materials
- The virtual field trip made me want to visit the real area

Section 9

User Experience

[**Likert**] Please rate the following statements - if you didn't play the game, answer as best you can based on the video

The game was:

- Simple
- Easy to understand
- Exciting
- Interesting
- Inventive
- Comfortable

Appendix D

Questionnaire Answers Graphs

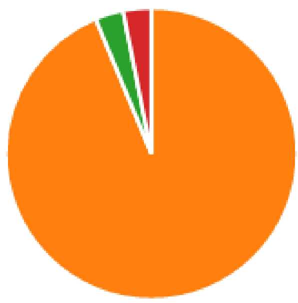
Forms Oppdal VR Virtual Field Trip - Saved ? SM

Oppdal VR Virtual Field Trip

32	12:12	Active	Ideas
Responses	Average time to complete	Status	

1. What is your age group?

0 - 20	0
21 - 35	30
36 - 50	1
50+	1



2. What describes you best?

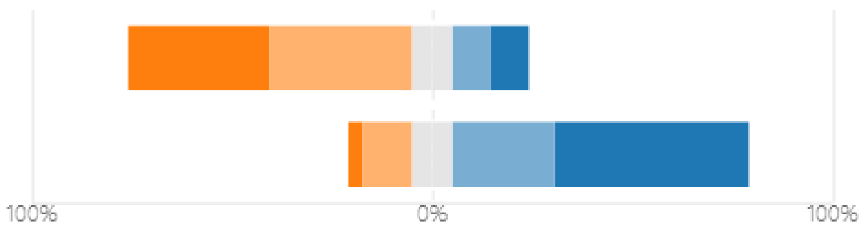
Student	17
Employed	14
Other	1

3. Please rate the following statements about you:

Strongly disagree Disagree Neutral Agree Strongly agree

I have played a lot of Virtual Reality (VR)

I enjoy playing video games



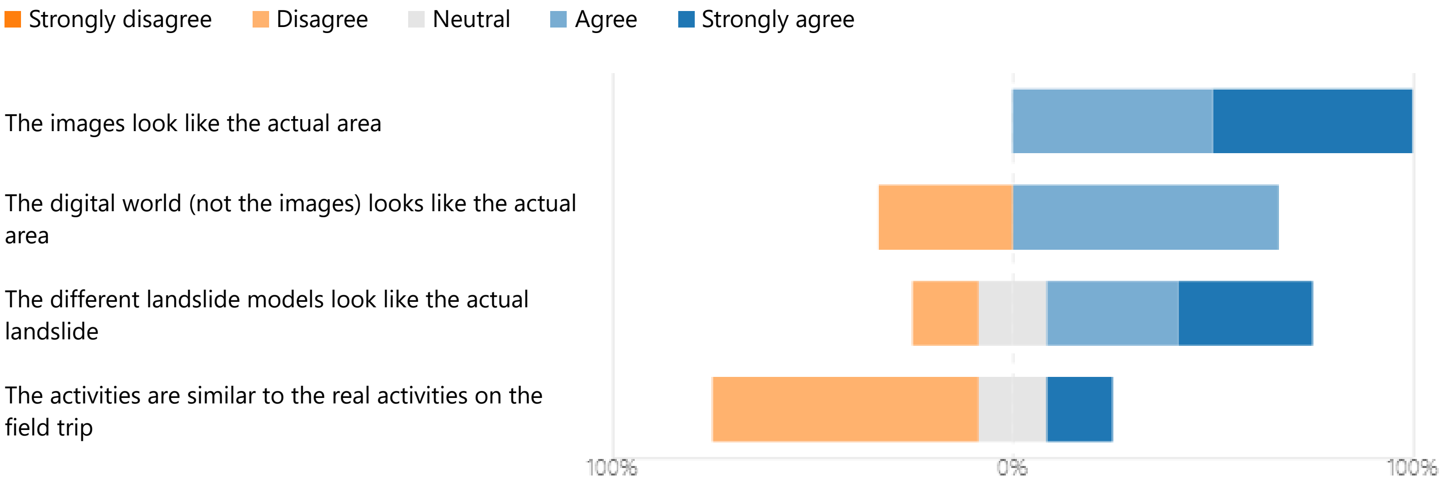
4. Do you study geography? (Or do you have a background in geography?)

Yes	12
No	20

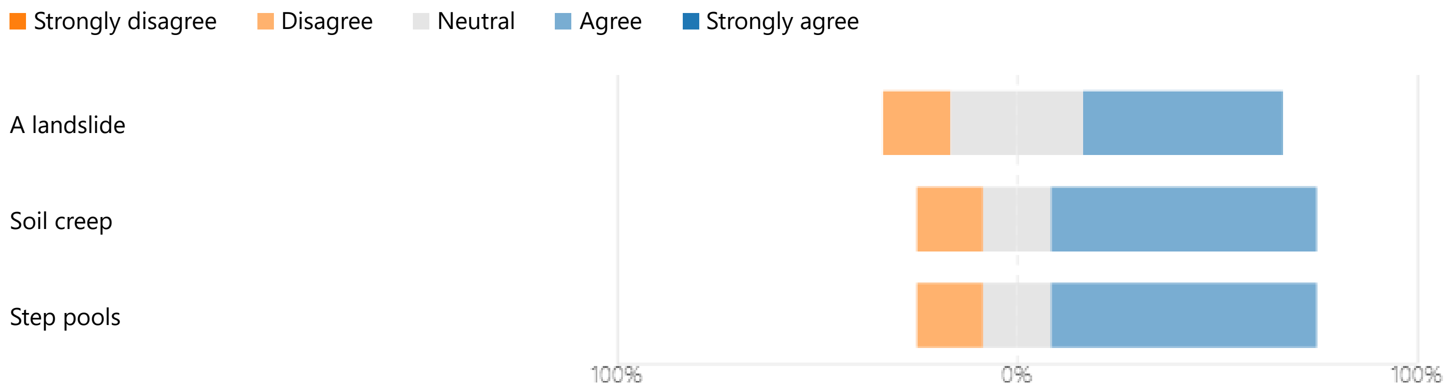
5. Have you been to Vekveselva in real life (through the NTNU course GEOG2012 - Field Course in Physical Geography)

Yes	6
No	26

6. Please rate the following statements about the game:



7. The game has improved my ability to identify landforms like:

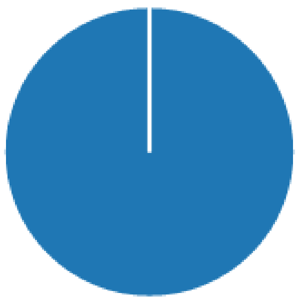


8. Did you play the game in VR or did you watch the video?

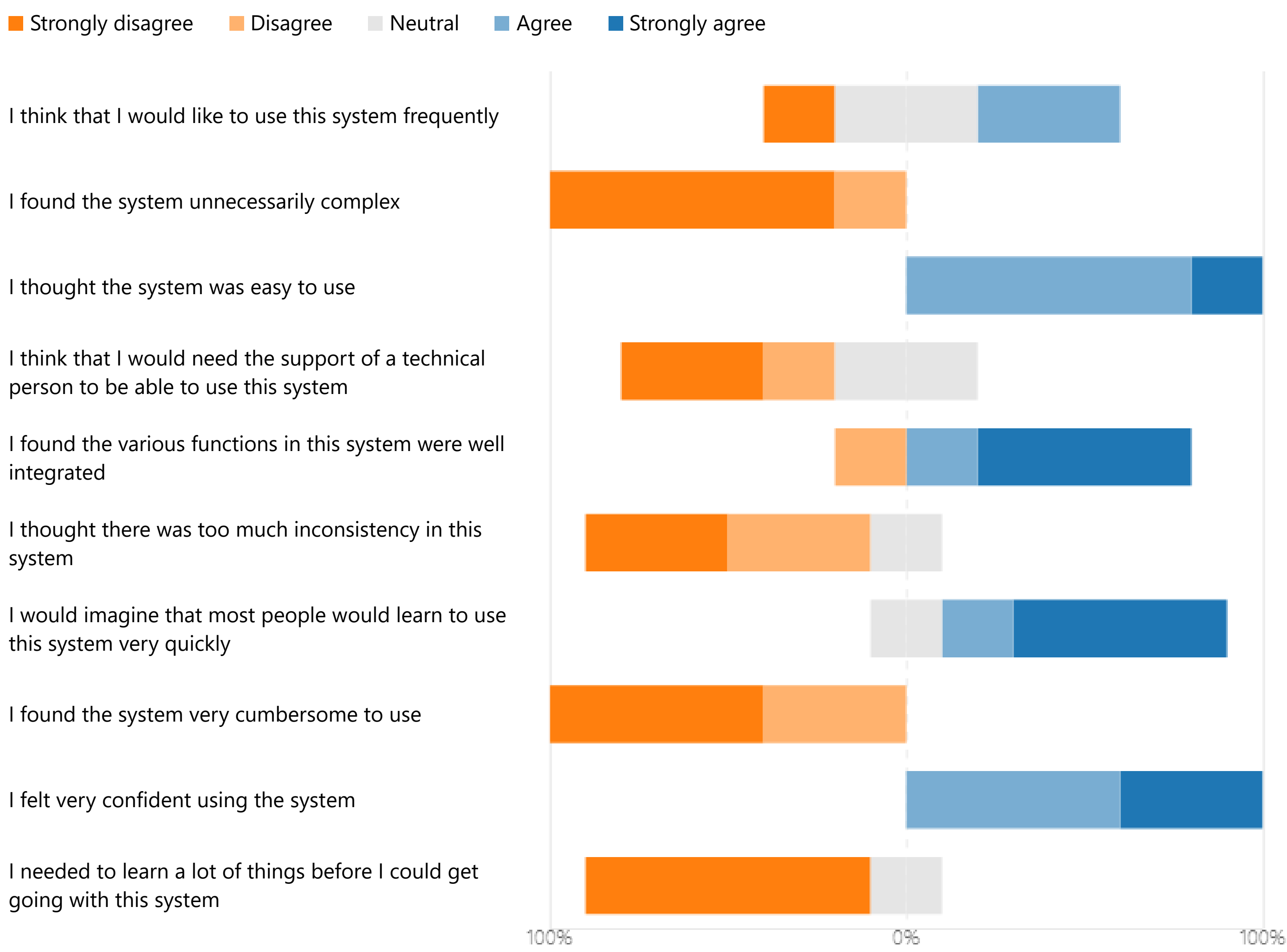
I played the game in VR	5
I watched the video	27

9. Did you use the omnidirectional treadmill or teleporting to move around?

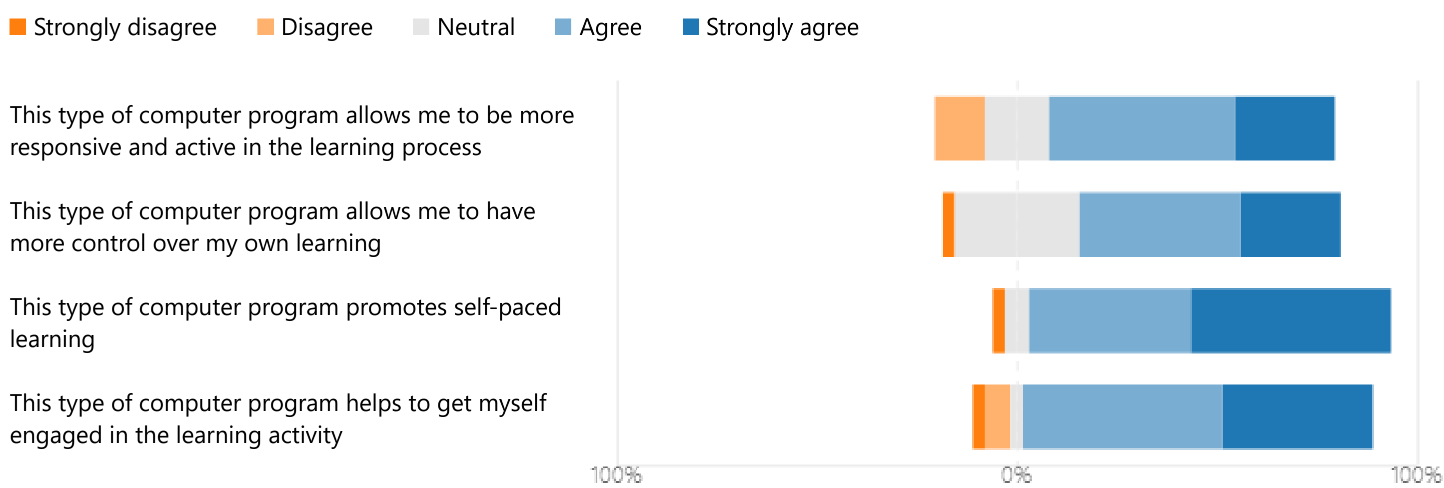
Teleporting	5
Omnidirectional treadmill	0



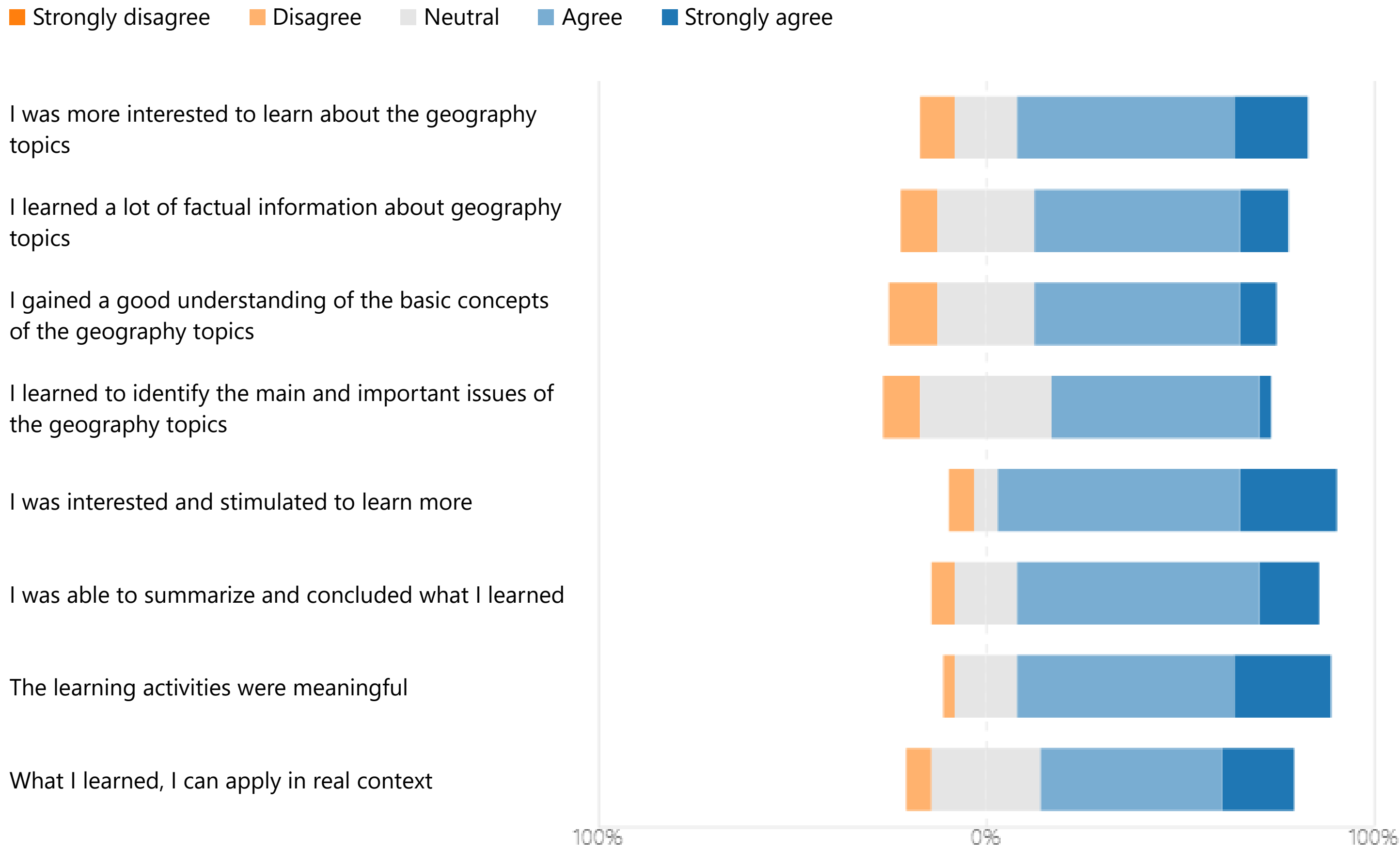
10. Please rate the following statements about the game:



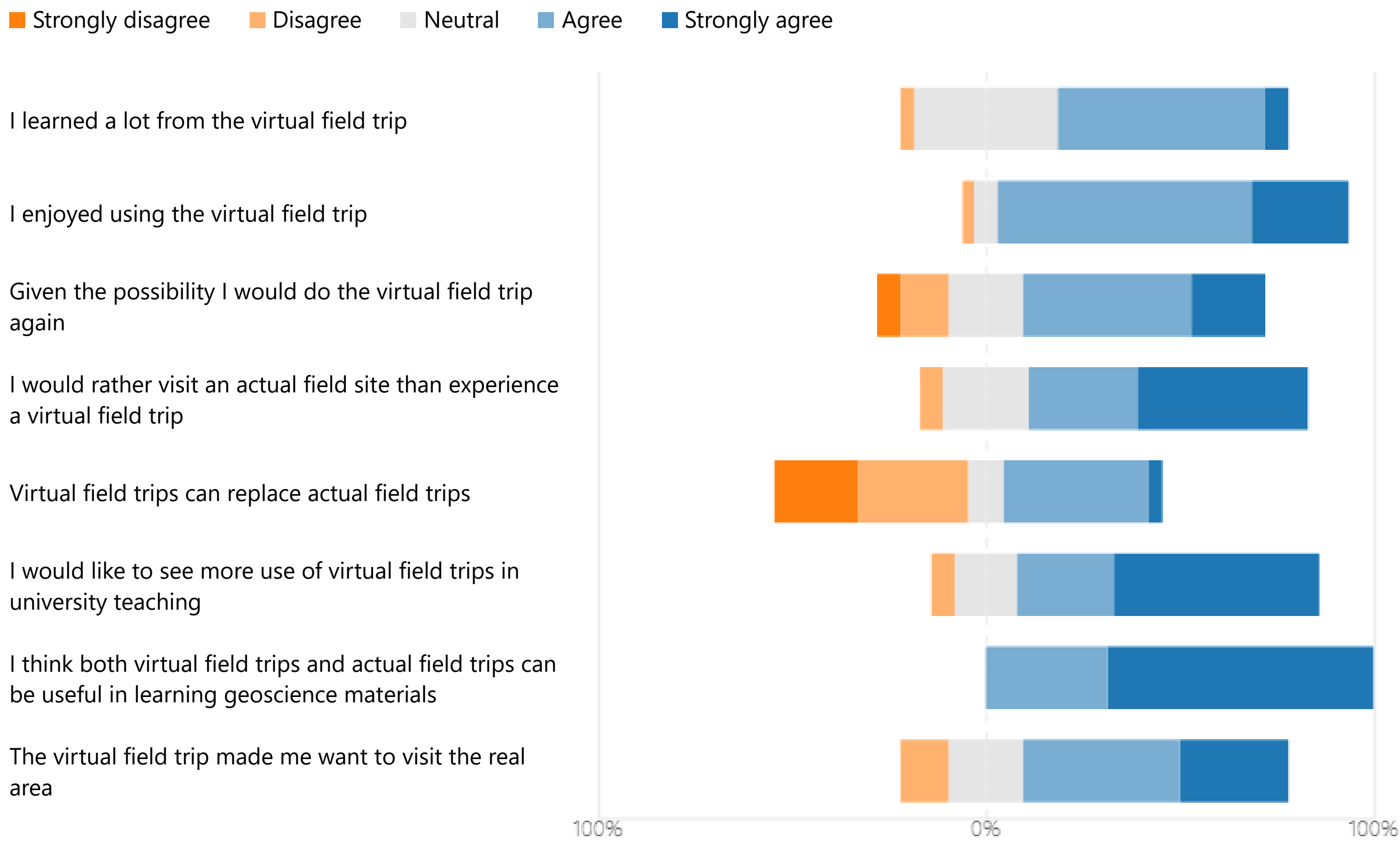
11. Rate the following statements about the game - if you didn't play the game, answer as best you can based on the video



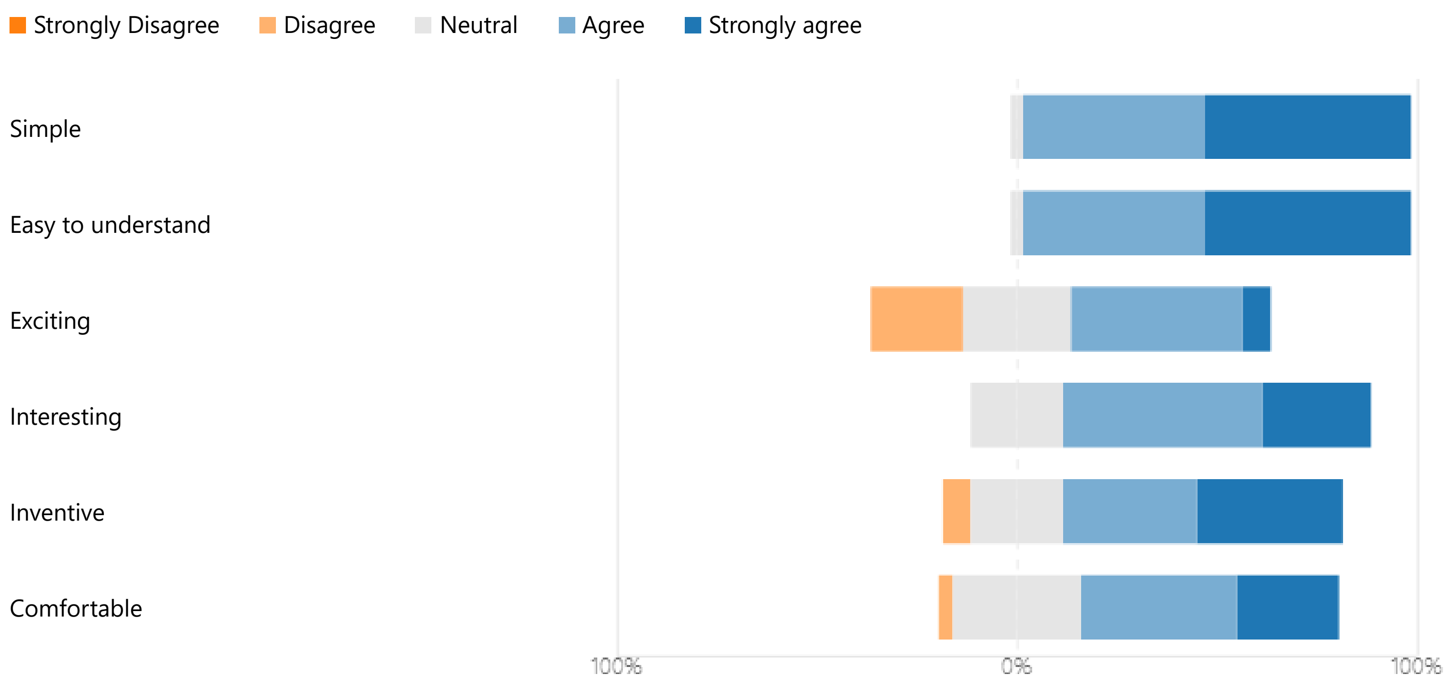
12. Rate the following statements about the game - if you didn't play the game, answer as best you can based on the video



13. Please rate the following statements - if you didn't play the game, answer as best you can based on the video (For clarification: the game is a virtual field trip)



14. Please rate the following statements - if you didn't play the game, answer as best you can based on the video



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Oppdal VR – an Immersive Virtual Field Trip for Field Course in Physical Geography

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