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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Virtual reality for remote collaborative learning in the context of the COVID-19 crisis

Master's thesis in Informatics
Supervisor: Ekaterina Prasolova-Førland and Monica Divitini
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2021/06/20

Abstract

This study seeks to explore the use of virtual reality as a tool for remote collaborative learning of a practical course at NTNU. The coronavirus has challenged our society at multiple levels. The education sector was one of the affected areas that needed to find ways to adapt to the change in circumstances. Education has shifted increasingly from the physical space to the virtual. Tools like video conferencing tools have helped many courses during this crisis, but has left other courses out. The subject of focus in this study is the archaeology study. This study line was in need of an alternative to practical real life lessons for excavations in the field as a consequence of the coronavirus. With the use of the design and creation strategy, this study aims to create and explore the use of a VR collaborative learning tool for archaeology students during a crisis like COVID-19. The application was created over the time span of several iterations of development and feedback, this as to provide and research the best possible application for this group of people. The findings resulting from this strategy concludes that virtual reality for practical education is a viable supplement for traditional education in archaeology courses. Furthermore; collaboration, gamification, and a simple user experience are features that should be the focus when developing such an application for this student group, when trying to maximize learning outcome. An education tool like this also provides advantages and use beyond the context of the coronavirus.

Acknowledgements

This thesis is the final project of a 5-year Masters of science degree in Informatics at Norges teknisk-naturvitenskapelige universitet (NTNU). It explores the potential of VR technology in collaborative education for archaeology students at NTNU.

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Acronyms

AFT Actual field trip. 14

FOV Field of View. 10

FPS Frames per second. 42

GUI Graphical user interface. 8

HMD Head Mounted Display. 10, 12

IDE Integrated development environment. 38

IHK Department of Historical and Classical Studies. 43, 47, 65

IMTEL Innovative Immersive Technologies for Learning. 6, 25, 29, 38, 42, 60

NTNU Norges teknisk-naturvitenskapelige universitet. iii, v, 5, 24, 30, 31, 72, 80, 82

PPI Pixels Per Inch. 10

UI User Interface. 8, 61, 70, 74

UiO Universitetet i Oslo. 50

UX User experience. 70, 71, 79

VFT Virtual field trip. 14

VR Virtual reality. v, 4, 12, 13, 15, 16, 20, 68, 70, 73, 77, 78, 81, 82

Glossary

Android An open source mobile operating system used on the oculus quest. 37

Blender An application used for processing and creation of 3d models. 38, 43

GitHub GitHub provides distributed version control and source code management functionality of Git, as well as its own features. 38

Kanban Kanban is a lean method where tasks are sorted into categories on a board. . 34, 37

Rider An IDE from JetBrains for code editing. It has integration with Unity. 38

Scrum Scrum is a framework for developing, delivering, and sustaining complex software products. 32, 34

Unity A game engine used for development of 3d applications. 37, 38

Chapter 1

Introduction

1.1 Context

The COVID-19 virus has made it apparent how vulnerable our society is to a situation like a pandemic. COVID-19 has made physical gatherings of people challenging and impractical. The education sector has largely been forced to conduct lectures and meetings over the internet, through video conferencing tools.

Using these tools over the more traditional ones brings with it several drawbacks. Among them, and the center of this study, is the inability to do more practical subjects. This is a huge detriment to those courses who are centered around doing practical work.

VR is one of the technologies that may have the potential to solve these problems. Current VR technology allows us to place people into environments of their own making, and creating a sense of presence not felt in typical video conferencing tools.

The use of VR during the pandemic has already been explored to some degree [1] [2]. This technology has educational value to students and ”takes them to places that are either difficult, or sometimes impossible, to access in real-life, e.g. space studies, archeology courses, medical education, chemical engineering and aviation training“[3]. This use enables hands-on, immersive, interactive and engaged learning activities for students. The increased use of VR for recreational purposes has also made VR technology available to a greater audience, increasing the viability of usage of educational tools in VR.

1.2 Purpose

The purpose of this study is to explore VR as a potential education tool. More specifically, on VR education in subjects where the work is both practical and collaborative. An application will be developed as a part of the design and creation strategy chosen in this thesis. This is done to get a more practically aligned answer and to learn what makes up a good VR education tool by iteratively creating one.

This study and the development of the corresponding application will be supported by both qualitative and quantitative data collection. The quantitative data will be collected from questionnaires, while the qualitative data will be gathered from observations, textual answers, and interviews.

The application will be focused on a practical excursion where a group of students will learn together by doing a task they normally would do in person. The will be to discover how well a VR application can replace the physical environment of more traditional education, both in terms of learning outcome and the immersive experience. Effort will be placed on uncovering the design patterns that maximize these factors.

With this purpose in mind, here are the three research questions:

- **RQ1:** In the context of COVID-19, can VR be used as a supplement for traditional education?
- **RQ2:** What advantages and disadvantages does a VR remote collaboration education tool provide to archaeological education?
- **RQ3:** How should one develop a practical collaborative VR application for archaeology education?

To answer these research questions the plan is to first explore other solutions, programs, and related papers. Then, using principles others have used before, the aim is to design and create an application that will help answer these questions. The creation of this app will be divided into 3 phases. The first phase will be exploratory, requirements and areas of research interest will be identified in this phase. The second phase will be where the application is developed. Development in this phase will be done in several iterations of creation and feedback. In the last phase an evaluation of the application and research questions will be done, this is after the development has finished.

1.3 Motivation

I starting reading about this thesis in august of 2019, a few months into the coronavirus lockdown in Norway. The lockdown had already left its marks on the everyday life of a lot of people, including me. At this point I already had some experience developing VR applications from my bachelor thesis. Creating something to help people in this situation and at the same time further exploring the potential of VR technology appealed to me.

When choosing my masters thesis it was important to me that the thesis solved some practical problems that people would find useful. Of course, most theses contribute to a field, but I wanted to contribute more directly by developing a useful application as well as doing research in a relevant field. This thesis was an opportunity to achieve this.

Exploring the possibility of using VR in practical education was of interest not only because it solved some real problem, but because it was future-oriented. It is the authors belief that the use of remote teaching tools and working from home will increase in the future. Exploring problems associated with this change from the physical to the virtual was interesting.

1.4 COVID-19

The corona virus was a virus that first appeared at the start of 2020. The virus quickly spread globally after its first discovery in China. COVID-19 came to Norway around February of the same year. The coronavirus is a highly contagious virus and has a relatively high mortality rate, especially for people in exposed demographics (i.e: the elderly or those with preexisting conditions).

As a means to combat the virus, Norway, and other countries tried to limit the spread of the virus by limiting social contact between people. The 12 of march 2020 became known as the day when Norway implemented the strictest measures ever done since war time. Some of these measures included working from home, studying from home, and a limit to the amount of people an individual could see in a week. Due to these measures, the education sector had to move most of its activities online for significant portions of the school year.

This change to virtual remote education happened almost overnight in some cases. Institutions globally had very little time to prepare measures for a remote teaching regime [4]. Those students who were in transition between different phases of education were particularly vulnerable when assessments and end-term exams were changed or in some cases cancelled.

Video lecture programs was a popular tool used as a replacement for physical attendance in the classroom. These programs made it possible for teachers to see and hear their students while they presented their lectures. This made it possible for education to continue to some extent, but it also limited certain types of activities, like those subjects more practically aligned. There is also a loss of interaction at a social level between the students and the teacher when teaching using video conferencing tools. Early studies into this area report that many teachers found difficulties motivating and creating an inspiring classroom when using online tools. [5]

COVID-19 had an immediate effect on how we go about our daily lives. A significant amount of people were affected by the reduced personal freedom, financial losses, and conflicting messages from authorities [6]. These factors contributed to widespread emotional distress and increased risk of psychiatric illnesses, especially for vulnerable groups like adolescents and minority groups. These effects may be expressed as emotional isolation, insecurity, and confusion. Imposing quarantines on people separates them from the usual everyday routines ingrained into them [7].

Institutes of higher education were not sufficiently prepared for the abrupt shift to distance teaching. The disciplines most impacted were those who were dependent on laboratories or other physical equipment not available at home. These studies were often limited to only theoretical work. The existence of technical infrastructure that supports educational activities and teaching staff ready to adapt are critical factors when measuring the quality of distance teaching provided [8]. VR technologies has the potential to support these technical infrastructures that study programs use to raise the quality of remote teaching. Providing environments that mimic equipment or laboratories only available at certain physical locations is also possible to replicate to a certain degree in VR.

1.5 Archaeology

The practical course chosen as a test case were ARK1001 [9] and ARK2002 [10] at NTNU. At the time, they were chosen based on these factors:

- Their need for alternative solutions in their practical lectures as a consequence of COVID-19
- The practical collaborative nature of the courses
- Access to students for testing and feedback purposes
- Their membership in the VR-Learn project

The VR-Learn project is a project that seeks to increase the activity-level of various courses at NTNU with the use of low-cost VR technologies as a tool for learning. It seeks to do this though the use of increased virtual field trips beyond the normal in the various courses tied to it. The two archaeology courses mentioned above are part of this project.

Several other courses were also considered, among them were; teaching related subjects, architectural subjects, ergo-therapy, and biology related courses. Archaeology proved the most convenient primarily because of where its faculty was located and because it met all of the other requirements.

After a discussion with a professor in historical studies at NTNU it was decided that the application to be developed was going to be modelling a stone age excavation site, since this was a part of the curriculum where alternate learning methods were needed.

1.6 Contributions

The contribution of this thesis to the field will be both insight into how VR works as a collaborative teaching tool and specifically on how a tool like this can work to support teaching during a situation where real-life teaching is limited.

The application that was developed in context with this thesis is also a contribution to the teaching tools available at the Department of Historical and Classical Studies. The application can be used in further research in this field, as well as more specific research into how archaeology and VR technology can be used together for greater effective learning.

As the application has been developed in a object oriented manner, editing and reusing part of the code in later projects is possible. The application can therefore be used as a framework for developing applications using similar functionalities in the future. Some of the functionalities that may prove useful in the future are the task management system and the excavation system. The task management system was a rework upon the existing system used at IMTEL. Compared to the earlier version of this system, this version allows easier implementation of tasks synchronized across a multiplayer session.

Chapter 2

Background

This section contains the background literature and explanations on the relevant surrounding concepts. This is necessary to fully understand the later sections.

2.1 Extended reality

Extended reality (XR) is the term referring to all the environments that combine both the virtual and the physical realities to various degrees. It is a continuous spectrum that ranges from the completely virtual world, to the real world. Therefore it is used as an umbrella term for virtual reality, augmented reality, and mixed reality. In this thesis we will focus on virtual reality, as the application and therefore the research will be done in a completely virtual environment.

2.1.1 Defining virtual reality

The term Virtual reality has many definitions depending on the source, there is no single true definition to it. The Norwegian lexicon has the following definition:

> "*Virtual reality is an illusion, commonly generated by using different types of information technology, that provide the user with the experience of being in another place, either imaginary or real.*" [11]

VR works by replacing the reality the user senses with a virtual one, usually through the visual and auditory senses. This is commonly done with a headset containing a screen and sensors to determine the users position in their environment. The user interacts with the virtual environment usually through two controllers, but sometimes using just their hands.

The virtual reality headset used in this study is the ”Oculus Quest“. The oculus quest is a VR headset that runs hardware very similar to mobile phones. The headset contains its own hardware making it possible to run VR applications without connecting the headset to an external computer. This makes the headset much easier to setup and use compared to other comparably priced VR headsets. It is also one of the more affordable VR headsets on the market, making it available to a much broader user-base.

Figure 2.1: The oculus quest with its two controllers. Source: www.komplett.no

2.1.2 UI in VR

In the field of human computer interaction, a User Interface (UI) is defined as the space where humans interact with machines. It is generally accepted that the goal when designing a user interface is to make it as enjoyable, efficient, and as easy to use as possible. In practice this often means that the user should provide as little input as possible to achieve the target purpose, while unwanted actions are minimized. UIs can interact with any of the six senses, usually multiple at once. One example of a commonly used user interface is the Graphical user interfaces (GUIs).

VR UIs have the potential to display a large amount of information in an easily understandable format. The need for specific UIs vary according to the requirements of the application and its purpose. Increasing complexity of a task usually entails different UI setups. Research into how UIs should be designed for archaeological learning applications are few. Studies has however been done into how UIs should be designed for VR educational architectural applications. Some common interaction principles should be transferable over to the field of archaeology.

Research done at Tongji University[12] indicates the preferred method of interaction with the environment in various contexts. The preferred navigational method between the ”Fishing mode“ and the ”Flying mode“ is the fishing mode. The fishing mode, shortly explained, is using a laser pointer with a downward curve to move about the environment. This method of navigation is also commonly used in other applications. Participants using the flying mode reported becoming dizzy after a while. Becoming dizzy during use is detrimental to the learning process, as the user loses focus on their task.

The study also shows that the grasp method is preferable over the proxy method of manipulating objects. The proxy method of manipulating objects uses an interface with a series of buttons to manipulate the objects positional and rotational axis. The grasp method is as the name entails a method of moving objects by ”grasping“ them with the controller. Although the study concludes that there was no significant preference among the participants, the completion rate of those using the grasp method was significantly higher.

Following these design principles and common methodologies in VR-UI design we have chosen to develop the app using the grasp method of manipulating objects, and the fishing method of navigation.

2.2 VR Headsets

This subsection contains a brief overview of the the availability and benefits of certain VR technologies at the current point in time.

We define VR technologies as the various VR platforms that the user can use and interact with. There is still a lot of innovation and new thinking going on in the VR market, as it still a relatively new market. Technologies are still rapidly changing and improving. Among the current top VR technologies are Oculus

Quest, Oculus Quest 2, Playstation VR, HTC VIVE Cosmos and Google Carboard. All of these are HMD's with their own unique hardware.

There are other solutions out there where one can use their mobile phone as a screen for VR, but the advantages of using these solutions have decreased over time. There are also other companies out there developing VR headsets, but the ones mentioned are some of the most popular on the market. This comes down to pricing, applications available on the platforms, and the overall immersion experienced.

What makes a VR headset popular can largely be condensed into these points:

- Degrees of freedom
- Quality of the display in terms of delay, FOV, update frequency and PPI
- Applications available on the platform
- Requirements for getting the headset running. Could be factors like external hardware or a large space. User experience is important here.
- Price. Most headsets also require external hardware, which can be quite expensive.

Headset	DOF	Display quality	Applications available	Requirement	Price
Quest	6	14.4ppi, 100° fov	Quest store, sidequest	Standalone unit	5799kr
Quest 2	6	ca 22ppi	Quest store, sidequest	Standalone unit	3999
Playstation VR	6	9.6ppi, 100° fov	PS store, limited	PS4, wired connection	3489kr
VIVE Cosmos	6	13ppi, 110° fov	Almost all of them	PC, wired connection	9299kr
Google Carboard	3	Phone	Phone Appstore	Relatively powerful phone	Phone + 136kr

Table 2.1: Table describing characteristics of available HMD's. Prices taken from komplett.no at 27.10.2020

After carefully evaluating cost, quality, and the ease of use, the decision was made to use the first generation Quest headset. A low-cost solution is the main priority for the stakeholders as the application will potentially be deployed in a classroom setting. The cost and maintenance should thus be carefully considered.

The Oculus Quest 2 performs better and has a lower price point than the Oculus Quest 1, but was not chosen as the availability of the Quest 2 was limited at the start of this project. If this was not the case the decision would have been made to go for the Oculus Quest 2 because of its better display and powerful hardware.

2.3 VR applications

VR applications are applications that make use of virtual reality to immerse the user in a virtual environment. Applications like these have been developed for a variety of sectors in the past, e.g: sports, medical use, education, fashion, and design work, among others.

A major obstacle when making a VR application remains the motion sickness problem. When a user is experiencing conflicting input from their senses, usually between the vestibular system (balance and spatial orientation) and the visual system, they can become dizzy and nauseated. This problem is especially prominent in users not accustomed to VR systems. When developing a VR application it is important that the application is designed in such a way as to avoid and prevent this problem as much as possible. Solutions previously explored includes making the user stationary, avoiding vertical movement, raising the fps of the application and other measures designed to guide the user away from problematic actions.

VR applications provide several advantages over normal desktop 3d applications. VR applications has been shown to provide users with an environment that makes the users more focused compared to regular 3d applications [13]. In the cited thesis, when comparing the learning engagement of 3d desktop applications and VR applications there was no significant difference. The VR application users were however more emotionally engaged, while the desktop application users were more analytical. Depending on the goal of the app, either method of presenting the environment is viable.

2.4 Collaboration in VR

VR collaboration applications allows users to connect and collaborate together remotely. These solutions commonly allows users to meet and communicate together with other people in the same virtual space. These virtual spaces usually allows the users in them to edit and manipulate objects in them, allowing the users to communicate and share ideas.

The most commonly known VR collaboration applications are the virtual meeting applications. These apps allow the users access to the usual meeting rooms, with functionality for bringing in presentations, images and other media from external sources. Examples of applications like these are: Mozilla hubs, VirBela, and AltspaceVR. All of these applications have been explored briefly for inspiration as a part of the background work. These popular solutions appeal to a large audience by allowing users to do most of what is possible in a virtual meeting space, with some additional functionalities depending on the platform. Special functionality like what this thesis seek to use is however not possible without developing a completely separate solution.

Working collaboratively remotely by use of VR technology has been studied extensively [14]. There has been an increased interest in VR as a tool for remote collaboration in recent years as the technology has evolved to become more accessible. These studies show that using VR as a collaboration tool has significant advantages over using a normal 2d display. They indicate that VR contribute to an increased immersiveness when using HMD's that in turn increases the feeling of presence and team-satisfaction when working collaboratively. The level of immersiveness was determined to be significantly affected by co-presence and self-location. Of these two factors, it was found that there was a significant correlation between self-location, the sense of presence of the self, and the perceived team-satisfaction. In practice, this means that when doing a collaborative task remotely it is an advantage using VR headsets over 2d displays when trying to achieve high team-satisfaction.

2.4.1 Principles for VR collaboration

According to an article on collaboration in VR learning games [15] the main principles to look out for and encourage in a VR collaboration platform are interdependence, thoughtful formation of groups, and individual accountability. Concepts and lessons from other collaborative tasks other than VR can also be useful, but not as relevant as principles directly related to VR collaboration.

Tasks that require working together to accomplish a goal fosters positive interdependence among the ones involved. Interdependence internally in a group is an important aspect to create when collaboration is the aim. Clear roles can also be useful when structuring collaboration in VR [16]. The addition of roles and rules comes at the cost of flexibility when developing a program with a variable amount of concurrent users.

According to the book ”Understanding Effects of Proximity on Collaboration“ [17], proximity is the main factor by which collaboration becomes easier. According to the book, proximity facilitates interpersonal interaction and awareness, which are important aspects of collaborative work. The book continues to describe that the current (at the time) computer communication technologies fail to provide the essential factors necessary to facilitate proximity. Some of the factors that affect this proximity aspect include visibility, audibility, co-presence, tangibility, and mobility. With the exception of tangibility, all of these factors for easier collaboration are achievable in a virtual reality environment.

2.5 Educational VR

Education in VR differs from normal traditional education in the way that it can provide students with access to education not available locally. Educational desktop 3d programs also has this advantage, but VRs ability to replace the interaction of a desktop PC with immersion is that it can bring the experience much closer to reality than any desktop 3d program can do [18]. This immersion is thought to reduce the ”cognitive overhead“, freeing a user from needing to focus on the semantics of the computer interface, allowing them full focus on the VR scenario [19].

Experiences that use VR can also provide perspectives on reality that allows powerful learning experiences [20]. Examples include viewing an object from an angle not normally seen or speeding up time to get a unique perspective. The ability to experience a situation multiple times is also an advantage VR has over normal on-site education [19]. Repeating a learning experience several times without any risk gives students more confidence in their own ability [21] without the stress experienced by potential failures.

In the following sections we will now explore some relevant sub-fields of educational VR. The chosen subjects are; field trips in VR, collaborative learning in VR, archaeology education in VR, and some related works.

2.5.1 Field trips in VR

Normal traditional field trips are journeys away from someones usual environment, this is the same for VR field trips. A field trip is usually done to get an experience or observe something not available at the groups home location. Field trips are commonly done to locations that are both culturally enriching and of educational value to the students. These trips could provide educational value in the form of increased critical thinking skills, higher tolerance levels, and increased historical empathy [22].

Immersive Virtual field trip (VFT) are increasingly becoming a popular choice for experiencing a remote place. Making a trip in the virtual has several advantages over doing it in real life. Among them are the reduced cost and the ability to go anywhere virtually modelled. The VFTs also do not change the education value compared to an Actual field trip (AFT). It is however significantly more enjoyable to the students than AFT [23]. As a part of the cited study, they also investigated the benefit of doing virtual field trips as a preparation for AFT. This is highly relevant in the case of this study. Responses to these question provided a significantly more positive response to virtual field trips as a preparation to actual field trips rather than only AFT. The study divided people into two groups, the ones trying both types of field trips and one trying only AFT. The group trying only the AFT focused on the feel of the authentic learning space, while the VFT group focused on specific features of the experience. One notable difference was that the VFT group were more focused on seeing and interacting with rocks rather than the actual feeling of touch. Overall, the VFT was more suitable in the way that it removed distractions from the environment and allowed the students to focus on learning.

2.5.2 Collaborative learning in VR

Collaborative learning in VR is a combination of the fields of Collaboration in VR and Teaching in VR. As a combination of two other fields, collaborative learning aims to provide a collaborative educational experience with the use of virtual reality technologies. A virtual classroom with a standard students and teacher setup can be considered a combination of these two fields.

The advantage of combining teaching and collaboration in VR has been explored in medical education in the past. According to one study [24], the use of collaborative educational VR applications in health education may improve knowledge transfer from one person to another. It may also deliver cost-efficient, safe, and effective learning. The learning method employed in the study was also considered helpful for students to retain information learned. A knowledge test performed both before and after the VR remote education lesson also showed a significant increase in scores from pretest to posttest for laymen, with a smaller increase for health students. Although this study did not identify any statistically significant results, their findings matched the general literature in the field; the use of VR can play an important role in health education as it is engaging, useful, enjoyable, and has a positive impact on learning.

Another study into collaborative learning in VR evaluated the technology when in use by cross-disciplinary teams when they were distributed across several locations, this is especially relevant for a situation like COVID-19 [25]. From their experience it is believed that VR is useful for collaborative tasks when it includes visual and 3D interaction, but not when it comes to programming in collaboration (technically demanding tasks). The overhead of working in VR is thought to be greater than the benefit of presence the user gets from it when collaboration on these tasks. Combining work inside and outside VR was also a challenge, especially when part of the group was in VR and another was out of VR having a conversation. Overall, the study claims that the students stated that they improved their teamwork skills, collaboration skills, and enjoyed the experience.

Collaborative learning in VR has also been done in other desktop 3d-application in the past, for example in Second-Life [26]. This study explores several virtual museums that have been created in Second Life for educational purposes. Museums like International Spaceflight Museum, the Second Louvre Museum, and the Bayside Beach Galleria Museum of Contemporary Art were modelled in the virtual environment. These museums provide a collaborative learning environment for visitors. Many of these virtual environments were developed with museum education and students as their primary audiences, and has as a consequence placed emphasis on traditional learning activities.

2.5.3 Archaeology education in VR

The combination of education, archaeology and virtual reality is a field that has not been explored much. Most papers in the area of archaeology and VR focus on the ability of VR to explore modelled historical sites which are difficult to explore in reality. There has however been a formative study into the advantages of educational archaeology VR applications. This study proclaims that educational archaeological VR applications has several unique advantages [27]. Among them are:

- Increased physical engagement absent in traditional digital displays
- Opportunities outside a students normal experiences
- Virtual manipulation of objects through intuitive interactions

The overall response from the participants was that the experience was enjoyable and appealing. From the study the participants report low intrinsic and extraneous cognitive loads. Intrinsic cognitive load refers to the difficulty of performing specific tasks in the app, while extraneous load refers to the difficulty of understanding a certain concept when it is described/shown to the participant. The attention and satisfaction of the users were also quite high (7.42/9 and 7.67/9 respectively) [27]. This formative study shows that educational archaeology in VR is feasible and has educational value to users.

2.5.4 Related works

The following sections describe the related work within the field of educational VR archaeology. Primarily just one application provides most of the same features as in this project. A couple of other apps have been included as they have some relevant features.

VRchaeology

Figure 2.2: Screenshot from the VRchaeology application showing a user excavating a site

The closest project that resembles the aim of this teaching oriented application is the one developed by the university of Illinois [27], shown in figure 2.2. They have developed a VR archaeology platform for their students where the aim is to facilitate and enable students by giving them practical skills without going out in the field. Either because the site they wanted to explore no longer exists or because the cost of entry is too high. They also focus on the need for an affordable option for archaeology students with limited funds, as the excavation sites are seldom close to campus. A number of papers have either been proposed or written with this application as their focus [28].

One of the papers, cited above, evaluates the use of VR technology for teaching introductory archaeology. In their conclusion the paper points out three important standards when developing a VR game-based learning experience:

1. The importance of having an interactive and user-friendly VR interface that simulates realistic activities.
2. The importance of connecting the VR experience to the users prior experience in real world activities, using non-VR interfaces.
3. Third, providing the user with tasks explicitly relevant to the intended learning outcome.

From the user feedback they collected, the main concerns the participants pointed out was: the lack of ambient sound, the absence of a narrative to contextualize the VR experience, and the lack of other media to help them through the learning experience. It is important to note that these aspects are based on their unique application. Without knowing exactly how their VR-experience is set up it is likely that the feedback from the app developed in context with this thesis will be different. However, it is still useful to keep these points in mind while developing.

Pleito VR

Figure 2.3: Screenshot from the Pleito VR application showing cave art

Pleito VR is an archaeological VR application developed by the university of Central Lancashire. Its purpose is to help archaeologists explore and analyze archaeological data in a more immersive context. In Pleito VR the users explore a VR reconstruction of Pleito cave, a fragile rock-art site with limited accessibility [29]. Differing from the aim of this thesis, the aim of this application is not to teach students how to excavate an archaeological site, but to explore an already modelled one.

Although this study into how VR and archaeology combine is only partly relevant for this thesis, there are some useful points. They found that the use of co-location of users on the same site offered the advantage of allowing multiple users to visit a site together. This is not always possible when visiting fragile, inaccessible archaeological sites. Either because of the location of the site or that the site itself doesn't allow a large amount of simultaneous visitors.

The article concludes that the use of the technique known as ”Portable X-ray Fluorescence“ combined with advanced imaging processes makes it possible to analyse layers of painting that have occurred at the Pleito cave site over the years. This is shown in figure 2.3. This unique perspective and the tools VR provides would not have been possible when interacting with the real site. In this case VR provides an unique advantage in that it provides tools like these. This same idea could prove relevant for educational VR archaeology apps as well, as you can conjure tools and artifacts you wouldn’t necessarily have available to you in real life.

Virtual field trips

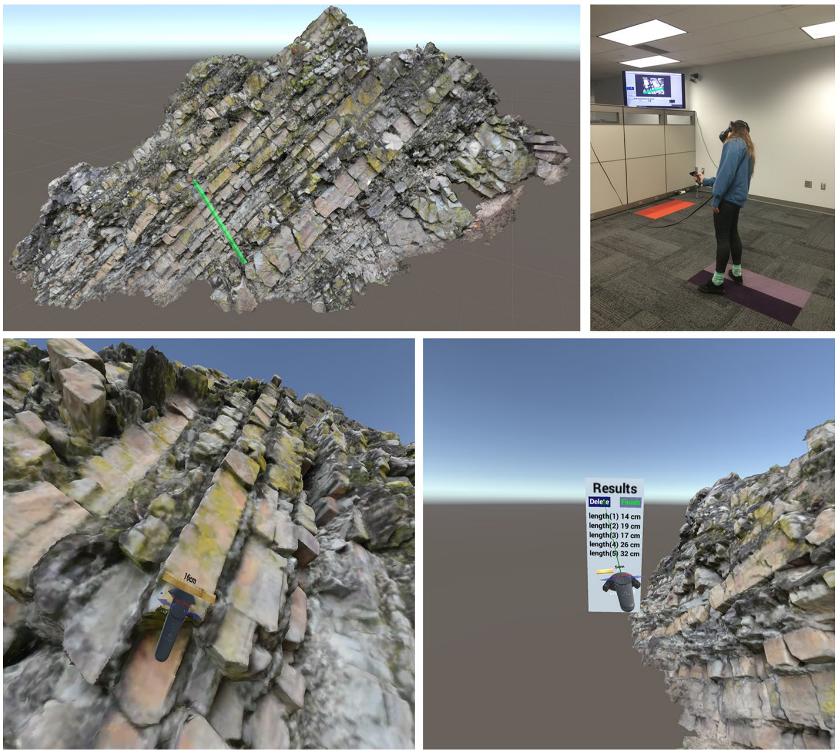

Figure 2.4: Klippel’s use of VR field trips at a part of the Bald Eagle formation. Retrieved from its corresponding paper.

Virtual field trips in VR is closely related to VR archaeological education. This application by Klipper was made to explore the educational value of virtual field trips versus actual field trips. In the application the students task is to measure and create a stratigraphic map of the bald eagle formation [30] by measuring the formations in the virtual model. An image of this activity is shown in figure 2.4.

In this study, three different levels of immersion using VR are tested out. The first is the usage of Oculus Go, second is the use of HTC Vive, and the third is the use of HTC Vive with additional tracking capabilities.

When testing the use of virtual field trips using a basic experience against an actual field trip, the study found a significantly higher appreciation for virtual field trips. This was measured in both enjoyment, lab grades, and learning experience [30]. Later, to corroborate their findings they added 360 images of the site and collected more open-ended responses. This survey confirmed their earlier findings and found that students were positive in favor towards virtual field trips as a preparation for actual field trips. This use of virtual trips or exercises to prepare for actual trips is something that has the potential to be transferable to archaeological education. The activities are of a practical nature, just as they would be on a archaeological virtual excavation site.

An attempted use of more inexpensive hardware (Oculus Go) with a lower immersion factor was also attempted using this application. The virtual field trip had to be re-developed to a degree for mobile devices, but this allowed them to test the application on a larger group of students. Preliminary results indicate a surprising success of the virtual field trip even though they had a loss in the immersion factor.

VR language learning application

Figure 2.5: Image from the VR Norwegian-language education app. Retrieved from its corresponding thesis.

Another VR collaboration application has been developed at NTNU before [31]. This application explores the combination of VR, language, collaboration, and teaching. A screenshot from the app is shown in figure 2.5. There are no archaeology features in this application, but it was included because of its collaboration and education aspects, which was relevant for this thesis. Compared to other collaborative learning applications this app was specifically chosen based on the access the author had to its program and source code.

In this app, the aim is to learn the Norwegian language through communicating with a partner and interacting with the environment. Users learn the language further by picking up objects lying around and having their names spoken aloud for them. There is also a speech recognition function built in, which makes it possible to say the name of an object in-game, and have it brought to you.

In the apps belonging thesis they found that 75% of the respondents felt that a VR class was more engaging than a regular class. This evidence was supported by the class teacher. Like in Pleito VR[29] participants reported a strong sense of co-location with the other people in the app. 87% reported that they felt that they were in the given environment. These reports are variable dependent on the application they were tested in, but they show the potential for VR collaborative learning when the applications are made immersive enough.

The teaching feature of the app allows a teacher to enter the room alongside students with different tools available to him/her. The role of the teacher is to guide the students around the environment and facilitate teaching. This element of allowing separating the roles of a teacher and the students is useful as it allows a more controlled environment in the app and ensures that the users stay on their assigned tasks instead of becoming preoccupied by exploring the app aimlessly.

Other VR Archaeology applications

There are some other applications out there that combine VR and archaeology, but these applications, like Pleito VR, do not focus on the teaching aspect, but rather on the exploration of recreations of historical sites. As of 07.04.2021, only VRchaeology seems to provide a VR environment for students to learn about and perform archaeological excavations. As these other programs focus more on the building of the 3d-models rather than the manipulation of the scene, they are not further explored in this study.

2.6 Gap in related work

According to the related work explored above, there are few applications that correspond to the research direction in this paper. The closest match is VRchaeology which allows students to excavate and train their skills in VR. It does not however provide collaboration functionality, an essential skill for archaeology students to master. Neither does it give students a portable platform to do these things. Other educational archaeology applications focus on providing the user with a real modelled area to explore, but not manipulate in any way. This was also not as relevant when considering the research direction.

The gap in the related work appears to be an application that provides these functionalities. Collaboration, remote learning, portable hardware, and excavation training is a combination of features that has not been explored before. Desktop applications with some of these features, like Second-Life and VirBela had limited interactivity and was therefore not candidates considered for use in this project.

Chapter 3

Method

This chapter details how the research process was conducted and why these methods were chosen. It details all the methods chosen, including the strategies, data generation, analysis, and evaluation.

Figure 3.1 is a diagram of the general research process where the sub-processes that are marked by a red box are the ones used in this thesis. This manner of structuring the research process is the one used by the book ”Researching Information Systems and Computing“[32].

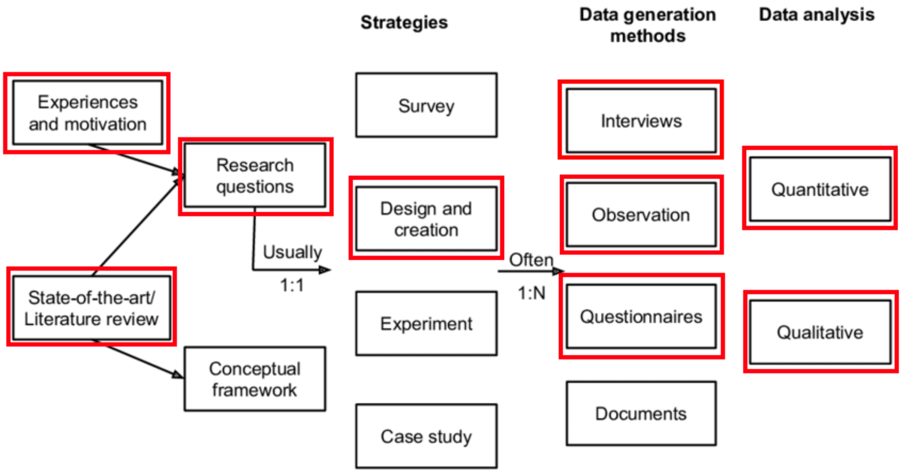

Figure 3.1: The general research process from the book ”Researching Information Systems and Computing“ [32]

3.1 The creation of a new VR collaborative teaching tool

The strategy to go for the design and creation method was made early in the process when it was discovered that there were no equivalent program at Norges teknisk-naturvitenskapelige universitets (NTNUs). An app was needed to explore these specific research questions and no equivalent existing app could be used for testing. In this strategy the product to be developed is called the artifact. In the case of this thesis, the application developed for the Department of Historical and Classical Studies is the artifact.

The main goal of this strategy is to develop knowledge that professionals of a discipline can use to create solutions for their specific problems. The aim is to achieve an understanding and knowledge of a problem by creating and applying an application of a designed artifact [33]. Re-evaluating the artifact and problem after each iteration of development makes it possible for the researcher to get a hold of the problem. This design loop is usually performed a couple of times before the finished artifact is delivered.

After each iteration of development on the artifact an evaluation is done to both determine the continued direction of development and to evaluate how the research questions are affected, this in turn raises the quality of the design process. During this step, the utility, efficacy and quality of the artifact must be shown. The contributions the artifact provides must be verifiable and the results reached through this method must be presented to the field in an understandable format suited for both people in the field and those outside it.

3.2 Data Generation

Data gathered in this thesis has been separated into three parts. The first part is the data gathered before actual development started. This was done to map the field of practical VR applications; to figure out the potential requirements, wanted features, and which study program which would be the focus of the thesis. Doing this data gathering before deciding on the focus of the thesis also helped as supplement in a period where gathering data in person was difficult.

Data gathered in the second and third parts was done during and after development, respectively. The decision to collect data during both of these steps were done with the aim of improving the application iteratively while at the same time collecting relevant data for the research questions. More focus was put into usability tests of the application during the second part of data collection.

All the data collected in this thesis is covered under the common NSD application under IMTEL. All personally identifying data will be anonymized and handled according to GDPR. Any data that can be traced back to an individual will be anonymized and kept confidential before being used for any research purposes. Initially, when checking to confirm that the thesis didn't collect any personal data the NSD's site was used[34].

This NSD form is included in appendix B.

3.2.1 Questionnaires

Questionnaires were used to provide feedback both before and after the research questions had been defined. These were of help in finding the specific questions to explore and finding out how to explore them.

The data collected from the questionnaires were also useful during the development process. Especially as they provided a uniform way of receiving feedback that was not as affected by circumstantial ways of asking or interpreting a question, like conversations and interviews are.

All the questionnaires used the Likert 5-point scale of rating responses in combination with text answers were the Likert scale didn't apply[35]. The combination of both of these types of responses provide both qualitative and quantitative data. An example of how the Likert scale was setup and presented in the questionnaires can be seen in figure 3.2. All the other questionnaires can be seen in appendix A.

3.2.2 Observations

The purpose of doing observations was to uncover what actually happened in a setting rather than what people thought or said happened. The observation of users was mostly done in a complete-observer manner. This meant that the observer was not participating in the phenomenon being experienced by the observed. The observer was also staying covert and acting unobtrusive to avoid influencing the behavior of the participants.

Vurder følgende uttalelser om tilstedeværelsen din i VR

	Helt uenig	Uenig	Verken eller	**Enig**	Helt enig
Jeg glemte hvor jeg var (i virkeligheten)	○	○	○	○	○
Jeg følte meg komfortabel i VR	○	○	○	○	○
Jeg følte meg tilstede på det virtuelle utgravningsfeltet	○	○	○	○	○

Figure 3.2: Example of questionnaire using Likert scale

Observations in combination with verbal feedback were used when users tested the application. This was especially relevant for when people outside the target audience tried out the application. Feedback in these cases were more focused on the usability aspects rather than the technical aspects of the program.

Usability is the measure of how well a user in a context can use the application to achieve their desired purpose. It is the measure of how efficiently and satisfactorily a user can achieve the programs purpose. The shape of the feedback received during these types of observations can be things like problems encountered during use, small comments from the user, or observations on how the user interacts with the system.

3.2.3 Interviews

Interviews were done in this thesis to gather qualitative data. The purpose of doing interviews was to better understand the opinions, experiences, and behavior of the subject persons, in this case the people testing the application. All of the interviews done in this thesis was done in combination with testing of the application. Questions during the interviews were usually asked in a open-ended manner as to allow collection of in depth information without influencing the subject towards a specific answer. Participants were guided back on topic if the conversation strayed too far from the planned topic.

Interviews were done with experts in the field of archaeology as well as normal students testing the application at the end of the project. This was done to get a varied response, both from people that have experience in the field, and those who do not.

3.3 Data analysis

The data gathered from observations and questionnaires will be of both qualitative and quantitative types. The observations and interviews generate qualitative data while the questionnaires generate both types. These two data types need to be processed in different manners before any conclusions can be drawn from them.

3.3.1 Quantitative data

The questionnaire generates quantitative data through the use of Likert scale type questions. The answers to these scale type questions will be converted to numerical representations. This makes it possible to look for patterns, compare progress, and draw conclusions. One common method of discovering patterns is by sequentially filtering on different attributes in each category of answers, trying to find a significant group of respondents with similar opinions.

When converting any Likert scale questions to numerical values in this study, the value range is from 1 to 5. 1 indicates that the person entirely disagrees with a statement while a 5 indicates that they entirely agree. A 3 implies that the respondent was neutral to the statement.

3.3.2 Qualitative data

Qualitative data was gathered from textual responses in the questionnaires as well as observations and interviews. Analysing qualitative data differs from analysing quantitative data in that the process of analysing is much more inductive. Each response needs to be analysed thoroughly to decode the meaning behind the response. After this step, some generalizations can be made to categorize each response and measure the broad opinion.

Chapter 4

Problem Definition Process

4.1 Starting out

Initially the problem description of the task at hand was quite broad. It started out with the idea of investigating the potential of collaborative learning in VR as a tool for education during the COVID-19 pandemic. In other words, the motivation of the thesis was clear, but not how to get to that goal.

Based on the description alone, there was no need to develop an application to test out the theories, but it was quickly decided upon that this would be necessary for a properly defined answer. It could have been possible to use already made general-use VR applications, but it would not have contributed nearly as much to the field as an app specially made for the purpose. There was also some motivation by the author to develop something useful for the university, as discussed in section 1.3.

An analysis of prior research and related works within VR applications was done, where focus was mainly applied to the most popular VR education tools and the research done under IMTEL. This was because of the ease of access to the resources used by these. There was also some interesting research already done in the direction of collaborative learning by some former students at IMTEL [31].

After getting an overview over the prior research done in the field and the apps that had been developed before, it was decided that the target group of the app would be students doing a practical subject at NTNU. Deciding to make this the target group helped shape the research direction.

This decision was followed by the initial exploration of the requirements such an application should have. Several surveys were done to gather information about what features should be prioritized, which course should be targeted, and what task was most suited to be done in VR. The first three surveys were done with the aim of gathering this information, which was especially relevant for RQ1. This period can be referred to as the first phase of the project. During this phase, data was gathered from people with a variety of backgrounds (no archaeology tests at this time). This group is referred to as the ”first study group“ in the stakeholders table, in section 4.3. The second and third phases of the project, explained further in section 6.1, explored the other RQs after the target course had been selected.

As explained in section 1.5, the decision was later made to choose an Archaeology course as the target group. Largely because of the course's practical collaborative nature, its part in the VR-Learn project, as well as its need for an alternative learning tool as a consequence of COVID-19.

4.2 Identifying specific research area

During the first phase of the project, data was gathered about the need for a VR platform for some practical subjects at NTNU. As explained above, the decision was later made to target the archaeology study program at NTNU. This decision was not only made on the premise that the archaeology program needed a VR platform, but also because research in this field was lacking. There was only one other similar application on the market, with some associated papers tied to it [28].

The combination of archaeology and VR had been explored to some extent, but combining these features with education, collaboration, COVID-19, and excavation appeared to be a new research area.

The use of existing platforms like Second Life, Virbela, and Mozilla Hubs was not a viable option for this study program. Although these applications are easier to setup and access, they do not have features that allow one to perform practical archaeological tasks. This is why the decision was made to develop a new application custom-made for archaeological education.

4.3 Stakeholders

According to the book ”Veien til suksess“[36] stakeholders should be identified and mapped according to two factors:

1. Their ability to affect the project.
2. Stakeholders who have interests that are affected by the project.

The book goes on to describe a table for getting an overview of these stakeholders. The approach to each stakeholder depends on which group they are placed in. The feedback of higher importance groups are prioritized over the other groups. These groups determine the projects scope and direction. Table 4.1 describes the stakeholders identified in this project.

		Stakeholders (demands and expectations)	
		Small	Large
Influence	Critical	Group 2: Archaeology students and the first study group	Group 1: Archaeology professor and archaeology faculty
	Marginal	Group 4: Other testers	Group 3: -

Table 4.1: Table showing an overview of the existing stakeholders

Group 1 contains stakeholders necessary for the completion of the project. Their contribution is critical to the project. They also have high demands and requirements in relation to the other groups. The archaeology professor was a specific contact at the department of Historical and Classical Studies at NTNU. Stakeholders in this group was closely monitored and involved in every major decision in the development.

Group 2 are stakeholders who are also important to the success of the project, but they have lesser demands and expectations than group 1. The archaeology students testing the application and the first study group were in this category. This was a prioritized group, measures to maintain their contribution and support was made.

Group 3 are stakeholders with no significant contributions to make. They have a marginal influence on the project but big expectations. No stakeholders have been identified in this group. Stakeholders in this group should be informed about their interests in the project, but not followed as closely as groups one and two.

Group 4 are those with no significant contributions and little to no expectations. No stakeholders in this group have been identified beyond testers that help discover bugs and improvements to the usability aspects. This was the least important group when considering requirements for the application.

4.4 Discovering system requirements

The system requirements have gone through continuous change throughout the writing of this study. The first iteration of requirements was set in the initial meeting with the archaeology professor at the department of Historical and Classical Studies. At that time the requirements were largely verbal and amounted to creating an experience similar to the one experienced by the author on a field trip together with this expert in archaeology.

The field trip was a trip out to an artificial ”excavation site“ where professional archaeologists attempted to create an excavation site for future students to dig out. During this field trip the tools and processes used by archaeologists were made clear. Information about this specific excavation site was collected in case the information was needed at a later date. Pictures and videos were taken as examples for recreating the site in VR.

The tables 4.2 and 4.3 details the updated functional requirements list reflkecting the requirements set during this trip. The list went through numerous changes and iterations. This means that some of the initial requirements have since been removed, and some have been added, as the scope of the application has changed. The multiplayer requirements was made into the separate table 4.3 for easier reading.

4.5 Prioritizing stories

As development began, a structure to keep control over which tasks that needed to be done first was needed. As the development of the application was done by one person, a commonly used strategy like Scrum was not suitable. Instead the

ID	Functional requirement description	Priority
ID1	As a player I should be able to dig in the ground using a tool	High
ID2	As a player I should be able to pick up objects from my environment.	High
ID4	As an archaeology student I should be able to apply my knowledge of archaeology in the app effectively, to uncover stone age objects from the ground.	Low
ID6	As an archaeology student I should be able to make intuitive sense of objects in the environment based on prior practical experience.	Low
ID7	As a user I should have the option to use tools like shovels, trowels, and buckets. Common tools used in archaeology.	High
ID11	The excavation site should be as graphically realistic as possible to closer emulate reality.	Medium
ID12	The excavation site and its environment should contain everyday objects usually found on a real excavation site. E.g: buckets, tools, tables.	High
ID13	The environment around the excavation site must be outside and look realistic.	High
ID14	As a player I should be able to move around and interact with the environment in a simple and intuitive manner.	Medium
ID16	The excavation site must contain stones from the stone age that would pass as real stone age tools in reality.	High
ID18	The excavation site should contain a tool to analyse and name the stones found at the excavation site.	Medium
ID22	The excavation site must use the grid pattern with corresponding ID's, just as it is done on real excavation sites.	Medium
ID23	As a user I should have tasks to measure my progress in the application when it comes to excavation.	Medium
ID24	The ground at the excavation site should be separated into multiple layers with lighter colors closer to rocks.	Medium
ID25	As a user I should be able to clean excavated stones with a brush	Low
ID26	As a user I should be able to view the distribution of excavated stones on a map	Low
ID27	As a user I should be able to use the program on a desktop PC with most of the same features that the Oculus Quest has.	Medium
ID28	As a user I should have tasks that help me learn how the coordinate system works.	Medium

Table 4.2: Table displaying the requirements as user stories

ID	Functional multiplayer requirement description	Priority
ID3	As a user I should be able to communicate with a partner in the app using my voice and hand gestures.	High
ID8	As a user I should be able to work together with coworkers connected to the same VR multiplayer session.	High
ID15	As a user I should be able to uniquely identify other players in the same session based on some identifying attribute (currently sound and color).	Medium
ID17	As a user I should be able to create another session of the game when the current ‘room’s are filled.	Low
ID20	As a user using a PC I should be able to use the app without VR gear. I should be able to join multiplayer sessions just like other people.	Medium
ID21	As a user playing in a multiplayer session I should see the same world as all the other people connected to the same session.	High

Table 4.3: Table displaying the multiplayer requirements as user stories

strategy was to go for a more informal version of iterative development called Kanban, with priorities for different stories instead. This was seen as a better choice as it was simpler to setup, more flexible to changes, and easier to maintain, as well as providing some of the same advantages as Scrum. The website *www.trello.com* was used to create boards and keep track of the stories. In the tables below the priorities were prioritized from High to low, where stories with a high priority was considered the most important and low priority was considered the least important. When deciding on the priorities of the different stories a number of factors were taken into account.

First, the fundamental framework to get the basic functionality of the app working was prioritized above all the other stories. These include the basic excavation site and the corresponding functionality that interfaces directly with it.

Secondly, those requirements set by the advising professor was prioritized. Additionally, those stories that are easy to add in at this point and are not required to make the basic premise of the app work are in this priority.

In third place are those stories considered ’extras‘. These stories are not necessary for fulfilling the objective of the app, but would be necessary for the app to be considered finished in the eyes of the developer. Other features can of course be added at a later point.

Chapter 5

Development process

This chapter details the development process A demonstration video of the finished application can be found at:

$$https : //youtu.be/L_jldTRDGyo$$

The video shows excavation from three different perspectives, but it does not showcase the multiplayer or the collaborative aspects of the app. There is however another player at the start of the video, showing that this feature is included.

5.1 Development requirements

The development requirements are detailed as stories in section 4.4. The stories were split into several iterations of development, according to the factors and prioritizations detailed in the same section.

Kanban was used as the lean development method for its low maintenance and ease of use. It is also an appropriate method for single-developer projects. A board on *www.Trello.com* was used to keep track of tasks remaining, current tasks, bugs, as well as finished tasks. Each individual task had a corresponding log making it easy to track when a task was started and finished.

5.2 Environment

The main development environment used was Unity. Unity is one of the most popular real-time game-development environments in use in the world today. It supports multiple platforms, making it easy to develop for multiple target platforms at once (e.g: Windows and Android for Oculus Quest). Unity also makes using 3rd party libraries easy through their asset store. This was an important factor when considering which game engine to use.

Blender was the chosen tool used for 3d modelling. It supports decimation of models as well as easy manipulation. The choice to go for blender was made simply on prior experience. The developer had no experience using other modelling tools and the modelling itself didn't need any of the advanced functionality found in other modelling programs.

For code editing the IDE Rider from JetBrains was chosen for its integration with the unity development environment. Rider provides tools such as code autocompletion, intelliSense, and analyzation of code for recognizing high resource-demanding functions. This was useful when optimizing the program for relatively weak hardware platforms, like the Oculus Quest.

GitHub was used for version control in the project. In the beginning Unity collaboration was used instead of GitHub because of its simplicity. The choice to migrate to GitHub was later made when the PC version of the application was developed. Developing for multiple platforms on one version of an application proved difficult because each platform required unique solutions to the same problems. The choice was therefore made to migrate from Unity collaboration to GitHub, wher multiple branches of the code could be maintained. The source code of the application cannot be found in any public repository at this time, it is held privately by the creator and by IMTEL at their Gitlab repository.

5.3 3rd party assets

By third party assets we imply assets taken from the Unity asset store. These assets were used either because they were required for certain functionalities in the app or because using them saved a lot of time. All of the 3rd party assets used in development is shown in table 5.1.

The XR interaction toolkit is a package developed by Unity that provides a framework for developing VR and XR applications. It contains a VR rig for room-scale environments, cross platform XR input support, and support for event handling, among other things.

Name	Description	Creator
XR Interaction Toolkit	XR framework for creating VR applications	Unity Technologies
Android Logcat	Asset that displays output from connected android devices	Unity Technologies
Photon Voice 2	Live voice communication between peers	Exit Games
Pun 2 - FREE	Easy multiplayer by synchronizing objects across peers	Exit Games
Nature Starter Kit 2	Trees, grass and bush models	Shapes
Folding Table and Chair PBR	Table and char models	devotid
Realistic Shovel Clean	Shovel model	Nollie Inward Game Assets

Table 5.1: Table of all 3rd party assets used in the application

Android Logcat was used for debugging purposes. This package makes it possible to get the logs of the oculus quest in real-time, as the code is being executed and tested on the hardware. This is useful for debugging problems that only become apparent on the Quest and not when testing in the editor.

Photon Voice 2 and Pun 2 - FREE are both used in the multiplayer component of the application. Photon Voice 2 enables voice communication between the peers in the application, both on PC and on the Oculus Quest. Pun 2 - FREE synchronizes all the multiplayer objects in the scene across all the connected clients. Everything from the location and rotational data of the stones and tools to excavation event handling is handled by this package.

The rest of the 3rd party assets are models for populating the scene with scenery. The developer had little experience in modelling objects and it was decided that to save time some of the scenery assets could be taken from the asset store.

5.4 Iterations

5.4.1 The first iteration

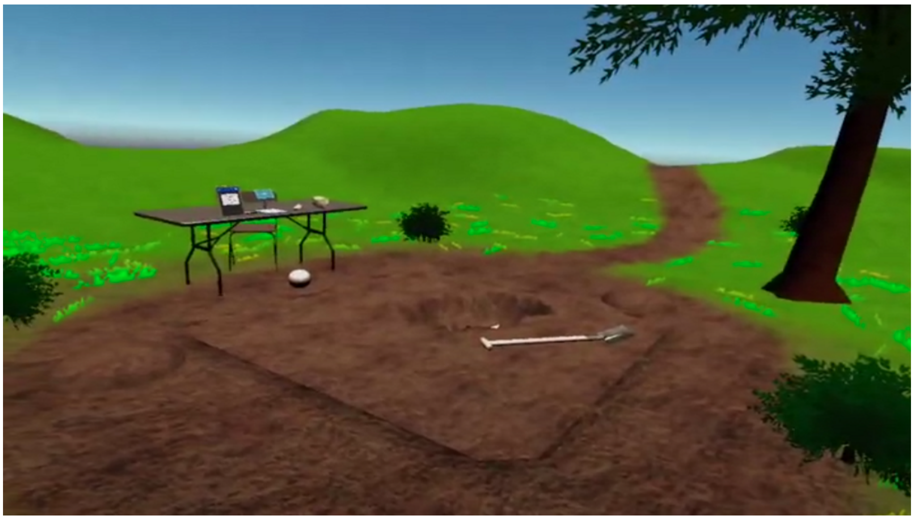

Figure 5.1: The first version of the application showing the excavation site

The first iteration was the largest development cycle when considering the time it took for development. The time to develop the first version was especially long because the initial requirements of the application were still being planned out. The development time required to make a minimum viable product also made this phase longer than the other phases. All of the separate parts of the application had to reach a minimum working state before the program could be used in any proper manner.

This iteration began when the practical subject the thesis would focus on was decided on and ended when the video of the first version of the working version was delivered to the advising professor for feedback purposes.

Objective

The objective of the first iteration was to develop a minimum viable product that had most of the core functionalities of the finished product. Finishing the fundamental excavation and VR experiences was the aim here. The planned functionalities can be seen in table 5.2. The decision to only focus on the fundamentals in the first version was made on purpose. The idea was that the basic stories that supported the other more complex stories had little chance of changing later in development. Doing it this way opened up the opportunity for the archaeology professor to give direction and feedback on the application before any costly mistakes were made.

ID	Functional multiplayer requirement description
ID1	As a player I should be able to dig in the ground using a tool.
ID2	As a player I should be able to pick up objects from my environment.
ID7	As a user I should have the option to use tools like shovels, trowels, and buckets. Common tools used in archaeology
ID13	The environment around the excavation site must be outside and look realistic.
ID14	As a player I should be able to move around and interact with the environment in a simple and intuitive manner.
ID16	The excavation site must contain stones from the stone age that would pass as real stone age tools in reality
ID18	The excavation site should contain a tool to analyse and name the stones found at the excavation site.

Table 5.2: Table displaying the stories planned for the first iteration

The procedural mesh

The procedural mesh was a big part of the first iteration as well as the project as a whole. Developing this asset took significant time as research on how to do it as well as attempting other methods were tried out. The procedural mesh is what the excavation dig site is made of. A mesh is a collection of vertices, edges, and faces that make up a 3d object. A procedural mesh is therefore a 3d object that is continuously modelled and created in-code while the program is running, instead of a previously made object.

The procedural mesh was made up of 40x40 vertices in a grid pattern that covers 4.1x4.1 meters. These vertices were connected together by triangles where four vertices were made into a quad which was then made up of two triangles. In total, the amount of triangles is 40*40*2 = 3200. Compared to the total amount of triangles the oculus quest 1 supports it was only 3.2% of the total. Making the mesh more detailed was just a matter of increasing the amount of vertices per width and length, this could easily be done by selecting the procedural mesh object in unity. The reasoning behind this detail level was that for every attempt to dig out the mesh, vertices has to be moved to mimic the digging action. This resulted in an update on the mesh, which is computationally demanding for the quest headset to do multiple times a second.

Testing was done to determine the optimal amount of detail in the mesh without impacting the performance of the app. The number of 40x40 was determined to be below the bar for where crashes would happen and above the FPS requirements.

Progress in the first iteration

All of the goals planned for this iteration were reached. Most of the development time went to developing the unique solution to the digging problem. Multiple solutions were explored, among them was one used by earlier students at IMTEL. This solution was deemed not detailed enough for the required level of detail in such a digging focused application. The solution decided upon was to generate a custom mesh of vertices in code. Tying this in with collision detection made the mesh responsive to the tools used on an excavation site.

Performance issues

During early development testing of the application it was discovered that the performance of the app on the quest hardware was poor. This was before most of the required objects were implemented into the app and was therefore of particular concern. There was a noticeable low FPS during play which quickly resulted in VR-sickness when moving around in VR.

After some analyzation using the profiling tool in Unity it was determined that the problem could be found in the amount of triangles rendered in the app. The official recommended max amount of triangles an app can contain using the oculus quest hardware was approximately 100k. At the time of testing this was closer to 250k. This requirement of 100k triangles in the scene is however largely dependent on what is rendered. As an example, a static scene with 100k triangles would perform better than a moving scene with the same amount of triangles.

The source of the problem was quickly found to be the stone-age rocks sourced from vitenskapsmuseet pages on Sketchfab [37]. These were scanned in from real-world objects and had a very high detail level. As an example, the ”Liten skiveøks i flint“ had 2.1 million triangles before processing it. Normally, Unity would optimize these models for the target platform automatically, but in this case that was not enough, To reduce the amount of triangles without sacrificing too much detail level, the program Blender was used. Reducing the triangle level was made easy by simply importing each object and using the ”decimate“ tool on them. The decimate tool works by progressively merging together vertices on the object, indirectly reducing the amount of triangles. The ”Liten skiveøks i flint“ was reduced to approximately 2% of its original detail level. This detail level did not result in an unidentifiable rock as the original detail level was so high. The decimation tool was also used on the trowel model, reducing triangles from 30k to 1.8k, increasing performance noticeably.

Feedback

Feedback from the contact person at the department of Historical and Classical Studies was generally positive. He remarked that the current state of the app was already something they could use at the Department of Historical and Classical Studies (IHK). However, he had some points where the app could be improved:

- A grid pattern needs to me made over the excavation site
- A clearer separation of layers in the ground.
- If time permits: A brush like tool to clean stones with
- The ability to view excavated stones on a map.

There was also some feedback received from testing done on students. These students were not archaeology students but their feedback was still valuable from a usability perspective. The following points were noted down when observing the usage patterns of these students:

- Generally there were not enough excavation tools for everyone to use.
- The controls were unclear to a large amount of users, and had to be explained numerous times.
- The pad explaining tasks and the analyzer machine were mostly ignored.

5.4.2 The second iteration

The second iteration started the week after the feedback from the archaeology expert at IHK had been received.

Figure 5.2: The second version of the application showing the grid pattern

Objective

The primary objective of this iteration was to use the feedback received from the first development cycle to develop the app in the direction indicated by the archaeology professor. The aim was also to integrate the multiplayer component with the app. This was prioritized higher than the professors demands as the multiplayer component and the collaboration it introduces was essential for further exploration of the research questions.

Another objective for this iteration was to develop a desktop version of the app. This version would allow people without access to VR equipment to use the application. When developing the desktop version the aim was to make it as close to the VR app as possible in terms of functionality. The stories planned for this iteration can be seen in table 5.3.

Progress in the second iteration

The objective of including multiplayer and a desktop app in this iteration was reached, but most of the points given by the professor was not achieved. In large part this was due to the amount of time it took to integrate all the assets already made with the different multiplayer components. It also took time to figure out the optimal solutions to certain of these components as the documentation and

ID	Functional multiplayer requirement description
ID4	As an archaeology student I should be able to apply my knowledge of archaeology in the app effectively, to uncover stone age objects from the ground.
ID6	As an archaeology student I should be able to make intuitive sense of objects in the environment based on prior practical experience
ID11	The excavation site should be as graphically realistic as possible to closer emulate reality.
ID12	The excavation site and its environment should contain everyday objects usually found on a real excavation site. E.g: buckets, tools, tables.
ID16	The excavation site must contain stones from the stone age that would pass as real stone age tools in reality
ID22	The excavation site must use the grid pattern with corresponding ID's, just as it is done on real excavation sites.
ID23	As a user I should have tasks to measure my progress in the application when it comes to excavation.
ID27	As a user I should be able to use the program on a desktop PC with most of the same features that the Oculus Quest has.
ID3	As a user I should be able to communicate with a partner in the app using my voice and hand gestures.
ID8	As a user I should be able to work together with coworkers connected to the same VR multiplayer session.
ID20	As a user using a PC I should be able to use the app without VR gear. I should be able to join multiplayer sessions just like other people
ID21	As a user playing in a multiplayer session I should see the same world as all the other people connected to the same session.

Table 5.3: Table displaying the stories planned for the second iteration

example code was of variable quality.

Desktop application

The desktop application was finished in this iteration. The aim of duplicating the experience in VR was largely reached. All of the functionality in the VR app was implemented in the desktop app as well. The difference between the two remains the immersion factor. The VR app allows the user to manipulate objects in a much more realistic and immersive manner. There is however an advantage to run the application on the desktop version when considering graphics.

A new control scheme was implemented for the desktop app. The method of controlling the character through WASD controls and mouse was used. A tutorial for the controls was included in the start lobby of the app.

Although the apps main target platform was the Oculus Quest, the decision to develop a build for Windows users was made in order to reach a larger group of people. The windows build does not have the same immersion factor, but was necessary as an alternative to the Quest in case test participants couldn't physically meet to try the Quest.

Feedback

During the second iteration feedback was given both during the development of the version and after its completion. In the middle of the iteration some feedback on the coordinate system implemented was received from the representative from the archaeology department. The feedback was on how the current coordinate system was implemented. He specified that the system was wrong according to how the system as used in practice. He reiterated that the system should use a coordinate system that starts at (100,100) instead of (0,0) and increases by 1 for each meter. Also, the X axis is north-bound while the Y axis is east-bound, opposite of what normally is used in mathematics and development. This misunderstanding of the coordinate system was fixed quickly as the setup work for this functionality had already been done.

Feedback was also received from user-testing. This time the feedback came from archaeology students. The feedback was positive, the testers had a positive experience not hampered by difficulties using the system. The only feedback relevant for the next iteration of development was some minor issues, not game-breaking bugs. Among these were comments like:

- ”Difficulties picking up some of the small rocks“
- ”Sometimes difficult to scroll in the menu“
- ”Shovel works all the way down to the ground, there is no need for the trowel“
- ”Difficulties reading the map over the excavation site“ (Text was too small)“
- ”Difficulties understanding the coordinate system“

5.4.3 The third iteration

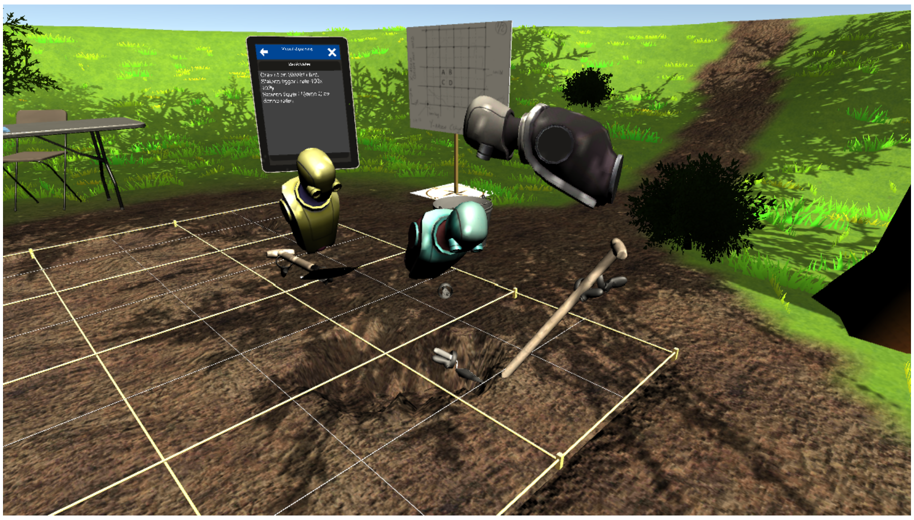

Figure 5.3: Image of version 3 of the app showing archaeology students cooperating to accomplish a task

Objective

Using the feedback from the archaeology students the aim was to improve upon the features already implemented. Any remaining time would go to adding features requested by the contact person at IHK. The stories planned out for this sprint can be seen in table 5.4.

Progress in the third iteration

An initial check of the problems experienced by the students in the last iteration was done immediately after the test. Most of the problems did not require any

ID	Functional multiplayer requirement description
ID26	As a user I should be able to view the distribution of excavated stones on a map
ID15	As a user I should be able to uniquely identify other players in the same session based on some identifying attribute (currently sound and color).
ID28	As a user I should have tasks that help me learn how the coordinate system works.

Table 5.4: Table displaying the stories planned for the third iteration

significant investment of time to fix, as their cause was quickly discovered.

The problem with picking up small objects was caused by some of the rocks not having their ownership transfer correctly when another person tried to takeover an object from another. This was fixed by simply changing the value of the ownership field in the Photon View script from ”Fixed“ to ”Takeover“. All the necessary work to make the takeover event work had already been done before so nothing else had to be changed.

The problem with the shovel was one of the more difficult ones. The statement from the student was that ”The shovel works all the way to the ground, and you therefore do not need to use the trowel“. This was not the intended purpose of the shovel as in real life you don’t use the shovel when getting to a certain depth in the ground. This is to avoid damaging any stone artifacts found at the excavation site. The problems cause was found to be a networking problem. What happened was that when the person attempted to dig with the shovel, the ground they excavated did not ”remove“ itself fast enough. This caused the shovel to ”dig“ at the same location again, removing dirt from that particular coordinate several times. This meant that when the dirt was finally removed from the coordinate, the depth at this position was dug several times below what it should have been. The cause of the ”multiple dig“ problem turned out to be network latency. As all networks have variable speed and latency, this is a problem when using the application on slow networks.

The solution was to update the mesh of the excavation site immediately upon digging in the excavation site for the client performing the action. The other clients would receive an update of the action after the performing client has updated the mesh locally. A consequence of doing it this way is that the action will now not be performed at the same time for the performing client vs all the other clients. As this is an event that is not particularly dependent on timing it is not that detrimental.

Some students reported having difficulties understanding the map and the coordinate system of the excavation site. As a response to this, the map was made larger and a post was made at the origin of the coordinate system, displaying (100x, 100y) at the origin for easier interpretation. An overview of version three of the application showing this is shown in figure 5.4.

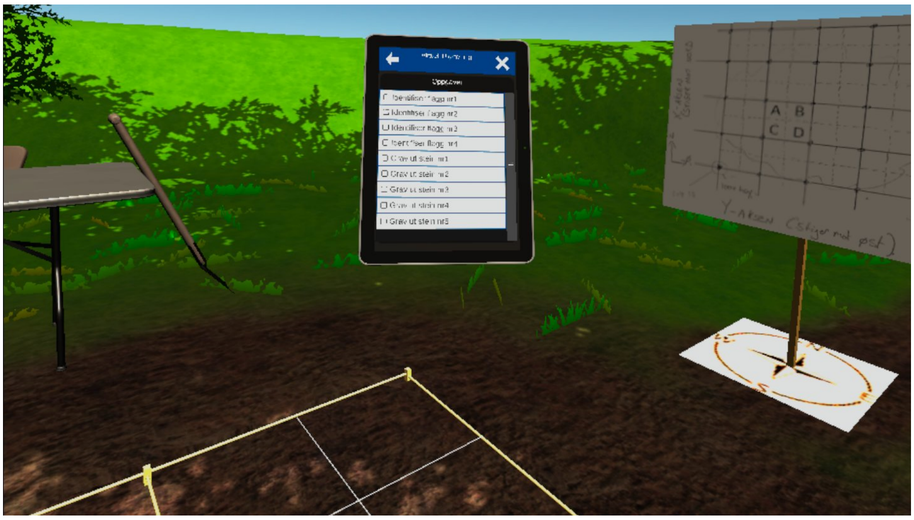

Figure 5.4: The third version of the app showcasing the excavation site map and the task menu

Additional features added

One of the requirements set by the primary stakeholder was that there should be some tasks where the students can identify specific coordinates at the excavation site. This functionality was added during this development cycle.

Some background functionality had to be added to make the additional tasks work, but the data structure closely followed the same structure used in the tasks for digging up stones from the excavation site. This makes adding additional unique tasks easier in the future as the structure for doing so is already complete. All of the tasks following this data-structure are synchronized across clients.

The current version of the coordinate identifying task shown in figure 5.5 works like this:

1. The user opens one of the coordinate identifying tasks in the menu
2. The cubes corresponding to each coordinate appears over the dig site
3. The user grabs onto the cube he/she thinks corresponds to the one given in the task
   a. The cube turns green if it is the correct coordinate
   b. The cube flashes red if the coordinate is wrong. The user repeats step three.
4. The task is now complete. If the user selects the task again they will get a message saying the task is already complete.

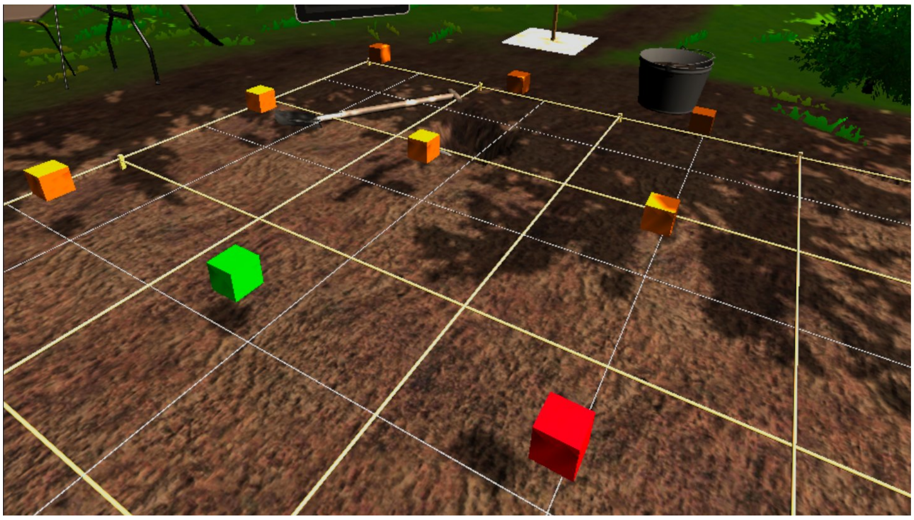

Figure 5.5: The third version of the app showing a particular coordinate cube. Red indicates a wrong choice and green a correct one.

Another feature requested was an overview of the distribution of excavated rocks on a map. This feature was implemented using the existing map and made to resemble the model used in a report from Universitetet i Oslo (UiO) [38], as requested.

Feedback

Feedback on this version was received from the target user-base; archaeology students. The response was generally positive. The tasks successfully taught the participants in the test the skills and concepts necessary for excavating the rock artifacts.

During testing there was only one new bug discovered. The bug concerned not being able to pick up rocks that other people had picked up prior to themselves. The bug appeared only occasionally and inconsistently when it did. This problem will be fixed before the final delivery.

5.5 Final version

5.5.1 Performance

The final version of the application was tested rigorously. Both the Windows version and the Oculus Quest version had been tested with varying amounts of players logged in. The windows version was tested on both a laptop as well as a desktop PC. The performance testing was done in a similar manner in all test-cases.

As the Oculus Quest has a display with a refresh rate of 72Hz and has frame-limiting, the FPS is maxed out at 72 no matter how many frames the application tries to send to the screen. All tests resulting in a FPS close to or at this value is as a consequence a good result. The Windows version of the app does not have a locked FPS and the results are therefore a lot higher than the Quest's version. Another difference between the Quest and Windows version is the quality settings. The Windows default quality settings is a lot higher than the Quests settings. The textures and shadows are therefore significantly more realistic in the Windows version.

The testing concluded that the application performs above the target requirements when measuring for FPS. The performance on the Oculus Quest consistently achieves an FPS of 72 with some small dips when loading in the scene. On windows the app achieves well above demand when not limited by V-Sync or other FPS-Limiters. An average person can only only see a difference up to 60 FPS on a physical monitor, there is therefore not a demand for higher FPS in this version

Platform	Hardware	Players	Average FPS	Max Triangles
Windows	3570k, GTX780, 16GB RAM	1	751 FPS	94.4k
Windows	3570k, GTX780, 16GB RAM	2	720 FPS	95.8k
Windows	7300HQ, GTX1050, 8GB RAM	1	175 FPS	94.4k
Windows	7300HQ, GTX1050, 8GB RAM	2	167 FPS	95.8k
Oculus Quest	-	1	72 FPS	94.4k
Oculus Quest	-	2	72 FPS	95.8k
Oculus Quest	-	3	72 FPS	97.2k

Table 5.5: Table displaying performance of the application in various contexts

of the app.

5.5.2 Features

The final version of the program allows a student to explore an archaeological environment and learn about the tools, maps, and coordinate system used at a real archaeological site. All all of this is possible to do together with other people, either other students, or a teacher. An image of this cooperation can be seen in figure 5.3.

Most of the stories in table 4.2 that were planned out at the start of the project, and the ones added at later stages were completed. Beyond these stories there were also a lot of small improvements suggested by testers during development that was implemented. The only functionalities not added at the end of the project were ID24 and ID25, shown in table 5.6.

ID	Functional multiplayer requirement description
ID24	The ground at the excavation site should be separated into multiple layers with lighter colors close to rocks
ID25	As a user I should be able to clean excavated stones with a brush

Table 5.6: Table displaying the stories not completed during development

Chapter 6

Findings

6.1 Survey overview

Nr	Section	Date	Place	Answers	Methods	Tried app
1	Section 6.2.1	31.08.20	Dragvoll	12 teaching students	Questionnaire	No
2	Section 6.2.1	24.09.20	Zoom	12 course participants	Questionnaire, Observations	No
3	Section 6.2.1	20.10.20	Dragvoll	4 teachers	Questionnaire, Observations	No
4	Section 6.2.2	03.02.21	Dragvoll	8 EiT students	Observations	Yes
5	Section 6.2.2	05.03.21	Dragvoll	3 Archaeology students	Questionnaire, Observations	Yes
6	Section 6.2.2	21.04.21	Dragvoll	4 Geography students	Observations	Yes
7	Section 6.2.3	12.05.21	Dragvoll	3 Archaeology students	Observations, Questionnaire	Yes
8	Section 6.2.3	27.05.21	Zoom	2 Archaeology experts	Interview	Yes (desktop)
9	Section 6.2.3	30.05.21	Lerkendal	4 students	Questionnaire, Observations, Interview	Yes

Table 6.1: Table listing where all the data was gathered and tests performed. Cyan: Before app, Orange: SUS relevant group, Cyan: Target group

The first section (lime) focuses primarily on figuring out which features are important in a collaborative VR application. These surveys were done before the project had been properly defined. Effort into discovering which study program which is of most interest to RQ1 was also done. This section was of most use when answering RQ1. In section two (orange) the data collection was focused around refining the application by testing usability with a SUS questionnaire, observing, and periodically checking if the development direction matched the expected result when factoring in the research questions. In the last section (cyan) SUS questionnaires were also used. Interviews, questionnaires, and observations of archaeology experts and students were done. Data relevant for RQ2 and RQ3 was mostly collected in the second (orange) and third (cyan) sections.

In the table above there is also a structure to the surveys based on where in the development process the surveys took place. The first three surveys were done before development had started, the three next were done during development, and the last three were done after development had finished.

6.2 The surveys in detail

The following sections details the context surrounding each survey done with the purpose to gather data. Findings especially relevant for the research questions are also noted down here.

All the surveys using equipment were done in a safe and secure manner. The VR headsets and controllers were cleaned with antibacterial towels and put into a UV chamber before and after each use. All users were also given a face covering mask to minimize contact between skin and the headsets. Also, at the Dragvoll imtel VR-lab everyone entering the lab had to use antibac when entering and register themselves using the rooms accompanying QR-code. These measures were part of our COVID-19 response.

6.2.1 Before development

Some surveys were done before the development of the application started. This was done to figure out what potential users of the app valued most in a VR archaeology application.

Initial survey

The first survey done was a questionnaire sent out to a group of students studying to become teachers, this was done when they tried out a number of VR applications at the IMTEL lab. The group consisted of 12 people, where 9 of them had no prior experience with VR before that day, the rest had only 'a little' experience. The students tried out the apps Stanford Ocean Acidification experience, Rising Sea Level in Trondheim (with treadmill), and Greenland Melting.

This survey was done before the research questions were properly defined. The questions in the survey was therefore more pointed towards what students would like in a VR application in terms of features. The students were also asked to rate their general learning experience through different learning formats, like VR, classroom education, video lectures, or self studying, these answers are shown in figure 6.1. As shown here, these participants favored VR learning over classroom, self study, and video lectures.

Figure 6.1: The impressions of teacher-students on different learning formats

In a later question, the participants indicated that they preferred the use of VR with practical lab exercises (11) over any of the other educational choices, shown in figure 6.2. This combines well with an earlier question where 91.7% agreed that VR can visualize many abstract concepts better than traditional tools and media. Combining both of these data points indicate that VR has the potential to be useful in practical courses where something needs to be visualized for a better understanding.

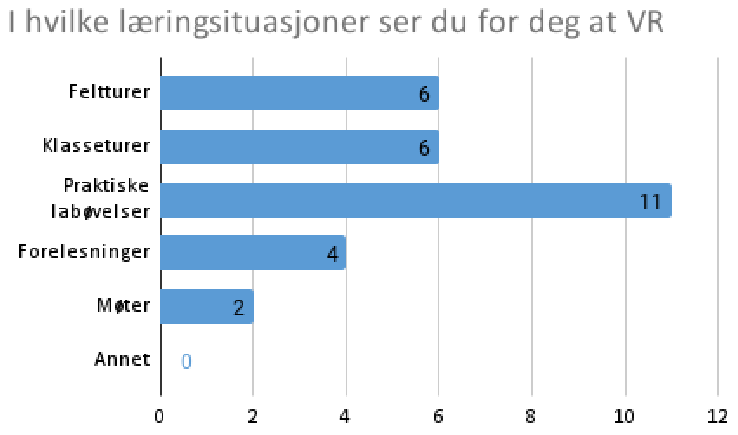

Figure 6.2: Which learning situations the teachers preferred VR to be used in

Second survey

The second survey was done in correlation with a course called "Fremtidens teknologier for digitalt samarbeid" (Future technologies for digital collaboration). The participants in the course was a group of 12 people, consisting of 7 temporarily unemployed and 5 employed people. During the course the participants tried out various well-known VR applications like AltSpaceVR, Second life, VirBela, and Mozilla hubs.

In the survey the participants were asked to pick their two favorite VR applications from those they had tried out. They then had to explain what made these apps better than the others. Finally they picked out the features they thought was most important in a VR app. This was done to figure out which features their favorite applications were missing.

Compared to the last survey, this one had a more even demographic, with experienced users who had tried out the technology for about a month before the survey. This made their feedback regarding wanted features in the VR application valuable, as it provides a different perspective.

Results indicated that the absolute most important trait for a VR application to have is ease-of-use. Both in user friendly menus as well as in the setup of the application, and intuitive controls. When answering the Likert scale, the ease of use categories were highly valued, shown in figure 6.3. As an example of this, when respondents were asked to rate which VR application they preferred 91.7% answered they preferred VirBela, which is one of the more intuitive and easy to use applications. Observations during use also support this. Users needed more help and was more engaged when using the more intuitive applications. One of the apps that performed poorest here was Second life.

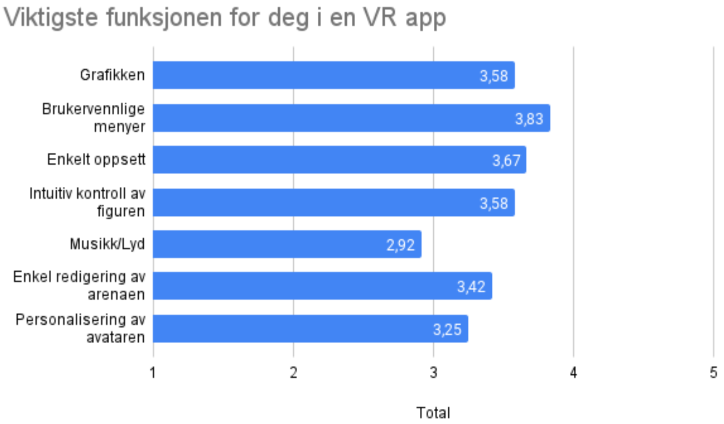

Figure 6.3: Results from the ”Fremtidens teknologier“ questionnaire

Third survey

The third survey was done on a group of teachers. The questions centered around figuring out what features were important for them in a teaching setting. This survey combined well with the prior survey, as we got the perspectives from both the established teachers and the teachers in-training.

The questionnaire was given to the teachers after they had tested some of the applications available at the IMTEL lab. Among the applications were the Stanford ocean acidification experience and the Greenland melting experience. Both of these applications are experience apps where the aim is for the user to learn something.

The number of respondents in this questionnaire is too small to conclude with anything on its own. The observations was more valuable in this survey, but the questionnaire does give a vague indication of the sentiment among the participants. In the questionnaire, the respondents were a little less enthusiastic about the possibility of using VR to do practical tasks when real-life lessons are impossible than the student-teachers (average of 3.5). They were also slightly supportive of the idea that VR could be used as a replacement for physical presence in the context of the coronavirus. The observations at the time also supported this. Conversations with the teachers discovered that they were interested in finding the practical use for VR in a teaching setting. One of the participants commented that the coronavirus had lowered the bar for attempting new solutions when it comes to student education.

6.2.2 During development

The following surveys gathered data during the development of the application. This iterative development inter-spaced with regular testing proved useful for discovering bugs and improvements relevant for the research questions.

Fourth survey

This survey was purely an observational survey, where data was collected on the usability and performance of the application on 8 students. These students were part of the VR ”village“ in the course ”Experts in Teamwork“ at NTNU. Eight students were tested in four groups with two in each group. This was the first time the multiplayer functionality was tested in any significant degree.

During observation, most of the students seemed to enjoy experimenting with the physical aspects of the application more than doing the tasks assigned to them. From comments from the students, the tasks were too hard to do as they had problems understanding where exactly the rocks were located. This could indicate that the UI and explanations that were in use at this time were too limited to understand the concepts the app tried to convey. Further tests to understand what the students need of media to understand these concepts will be explored, before a conclusion is drawn here.

Notes were taken on the behavior of the application and the students immersed in it during testing. Some bugs and inefficiencies in the usability aspects were discovered during observation. Most of the feedback from this session was used during the development of the second version of the app. Some of the more important points of feedback were:

- The need for a tutorial for controls in the beginning
- The need for voice communication between peers

- Some multiplayer bugs. E.g: Disabling people from stealing objects from each other.
- A better tutorial for understanding how to do the tasks

Fifth survey

The fifth survey was the first survey done with the target group, archaeology students. There were three participants in the testing and data gathering. The testing was done on Dragvoll at the imtel VR-lab there. All participants were given an oculus quest 1 headset and instructions on how to use them. They were then given the version two of the application. This was the version containing the tasks for excavating the site, but not with tasks for identifying cells.

The students were then given some instructions at the beginning of the testing on how to put on the headset and on how to control their in-game movement, after that they were told to collaborate to finish the tasks given them by the tablet in the simulator. During testing the observer refrained from giving directions and hints to the participants to avoid staining the observational data with preconceptions from the observer.

The data gathering in this survey was both from observations and from a questionnaire. Observations were useful in discovering usage patterns the users were unaware of, while the questionnaire was useful in giving statistical answers to questions not directly pertaining to the application.

Some of the most important points coming out of the observations was that the users were more focused on actually digging in the ground, rather than doing the tasks given to them. Even though the users were reminded to perform the tasks at the beginning they seemingly found digging the excavation site more fun. They did not follow the instructions they were given from the tablet and instead tried to dig out the whole excavation site. The reason the students went about the task in this way could be because they didn't understand the instructions on the tablet. The observations indicated that they did not understand their given tasks until some time had gone by. Questionnaire data did however indicate that at the end they understood the tasks they were given to a satisfactory degree (Question 1 in 6.4).

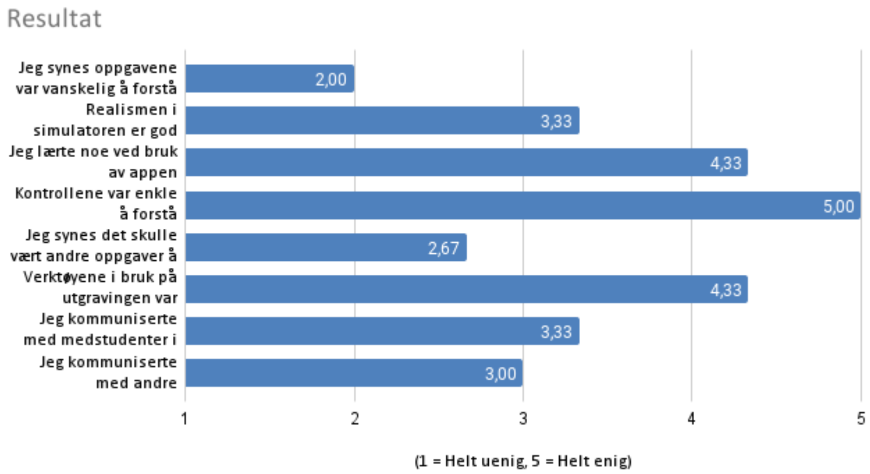

Figure 6.4: Partial results from survey 5

Another finding was that the collaboration between the participants could have been higher. The app itself should encourage and enforce collaboration, not rely on the users to decide to collaborate. A suggestion from one of the users was to force certain users in the program to use certain tools. In this way the users would be forced to collaborate to complete their tasks.

There were also some bugs and small improvements discovered during the session. Multiplayer testing made these apparent in a way single player testing could never do. This proved that bug-testing the multiplayer functionality without multiple users is difficult.

Sixth survey

This was a small study done to get feedback on the technical and the usability aspects of the application. Data was collected on four geography students with little to no prior experience with VR. Testing uncovered a bug involving the task menu in the application.

There was also comments made about the method of movement implemented. Two of the users wanted a different movement method involving the joystick on the controller. This requested feature had not been noted before. A possible reason for this could be that the two testers had immediately prior to trying the application tested another app with this movement style. This is most likely the case, as the preceding questionnaire and observations done during the two former surveys have noted that the current controls and menus were easy to understand, and worked according to the users expectations.

6.2.3 Evaluation: After development

The following surveys were done after the applications last features were added. A combination of usability and evaluation tests were done at this point. Both from archaeology students, archaeology professors, and regular students.

Seventh survey

This survey was performed on 3 archaeology students. Two of them were first year students while the last one was a third year student. In comparison to the last test on archaeology students, this test was done with version three of the app, the last version. New features in this version was the tasks for identifying cells and map markers for excavated rocks. Some general usability aspects tied to the map were also improved, to make understanding the coordinate grid easier.

The students were given the same instructions as in the fifth survey. Advice and help were only given to the users when it impaired their ability to test the app. The questionnaire was slightly different from the last questionnaire involving archaeology students. At the time, the decision to change the questionnaire was done because the questions of the last questionnaire didn't target the research questions particularly well. There was also some questionnaire questions that were transferred to the interview instead since they were too hard to interpret and answer using a Likert scale question.

The students did generally better than the last group of archaeology students. They needed less time to learn the coordinate system and cooperated to a greater degree. They were also more focused on digging out the specific squares where the rocks were compared to last time when they just dug out the whole area. This greater focus could be the result of the changes done to the UI since last time. The questionnaire data also supports this hypothesis. When asked the question "Jeg løste oppgavene sammen med de andre" the average of the responses had increased from 3,0 to 4,67, as seen in figure 6.5. This increase of cooperation could be the result of the improvements made to the program or simply be because of a better group dynamic.

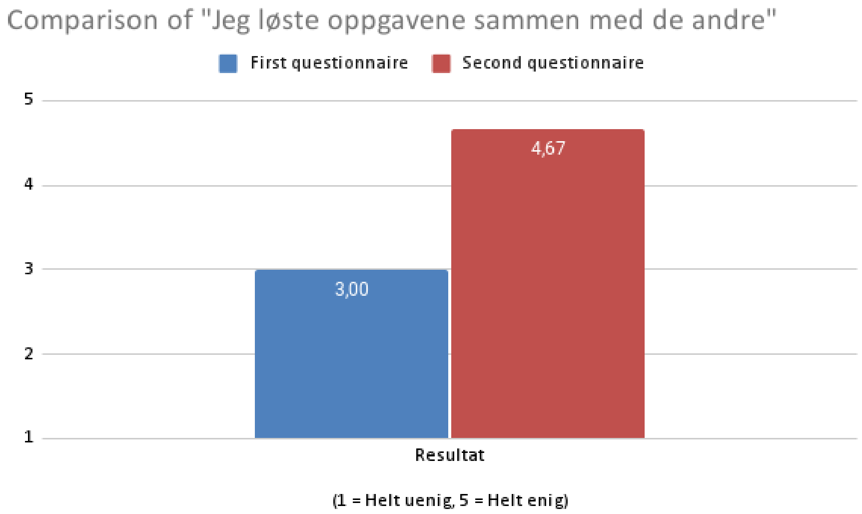

Figure 6.5: Comparison of results from one questionnaire to another

The data also indicates that the use of the VR application increases the users comfort with practical excavations and successfully teaches users concepts necessary for excavating in real life. Figure 6.6 shows the data on this. This data was also confirmed by informal interviews after the testing had taken place.

During the informal interview one of the participants commented that ”The application feels very game-like“. When commenting this he especially pointed out the task system and point tracking. This comment, combined with the question ”Doing the tasks were fun“ in the questionnaire could point to the experience of having fun being conductive for learning [39]. The experience of having fun when learning has been shown to have a positive effect on the learning process in past studies by motivating, reducing stress, and creating a state of relaxed alertness. This indicates that VR could be a good tool for training archaeology students in excavation practises.

Eighth survey

At the end of the project an evaluation was done with two professors from theIHK. The interview was done through zoom as there was a work from home policy in effect at that specific moment. Both of the professors had prior experience with VR, as they had experimented with the use of Google Cardboard headsets in education.

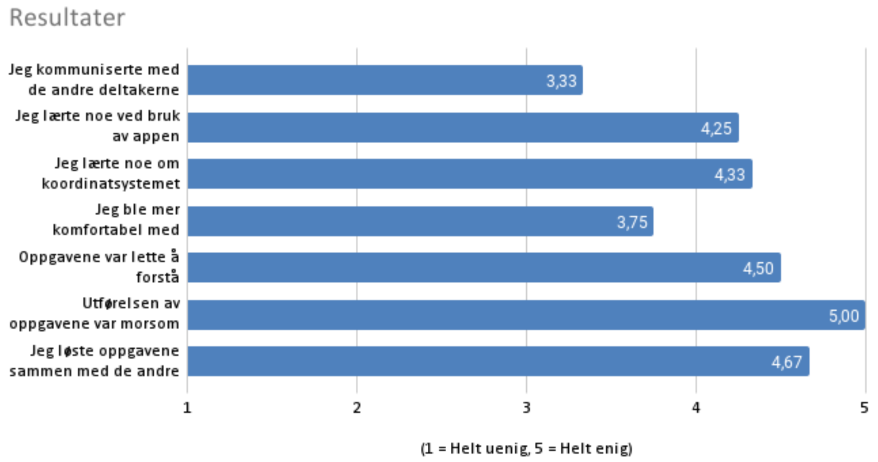

Figure 6.6: Extract from the questionnaire in the seventh survey

During the interview. the two professors went through a series of questions, testing, and then additional questions about the application at the end. The testing of the application was done using the desktop version of the app.

Before testing of the application began a series of general questions about VR archaeology was asked. Both professors expressed excitement about VR as a learning tool. One of the interviewees expressed that they were especially interested in the potential of VR to get students closer to cultural heritage sites and other unavailable sites. Another comment was that they hoped that students would use VR to get a little practical experience before going out in the field. Using VR education as a sort of bridge between theoretical and practical education.

Testing of the app was done on each individual participants laptop using the desktop version of the simulator. As the testing was done on the desktop version and not on a VR platform, the full experience of using VR was lacking. The immersive aspects were therefore not explored by the professors. The professors were guided through the various tasks and functionality of the simulator after they had been given a quick tutorial of how the controls worked.

After testing, questions about how they thought the application performed was asked. The response was that the learning experience should teach the students about a series of concepts needed to understand how a real excavation site is set up. One of the professors had the following to say: ”You can practice doing this now with VR that we otherwise couldn’t do, as setting up an exercise like this would be difficult in practice in the real world“.

At the end of the interview, features that they would want to see in the future was discussed. Among these were:

- The possibility for students to choose their own method of excavation. Evaluating the type of cultural site when deciding this would be the learning point here. Choices could be tools from excavators to shovels.
- Packaging of findings.
- Creation of ”Modules“ of content that connects with the curriculum.
- Recreating specific excavation sites where real life access is limited

Ninth survey

This was a final usability test done with four students of various backgrounds. The students went through testing of both the VR and the desktop version of the application before answering the questionnaire.

Like in all the other tests done, the students were left to figure out how the tasks were done. Help was only given when it hindered their ability to test the app. The students went into the test with no prior expectations of how the app worked beyond knowing that it was an archaeology excavation simulator. Once inside the app, they were told to do the tasks given to them on the tablet.

Observations of the students concluded that most of the controls came naturally to them after an initial period of time. All of the 9 tasks available in the program were finished after approximately 10-15 minutes. From observational data, some of the testers did more tasks than the others, indicating an uneven comprehension of the tasks. These individuals did not try to explain these concepts to others, as they had no interest or incentive to do so. In this case, the collaborative aspect of the tasks were lacking. Encouraging the participants to work together would have resulted in a higher average understanding among the participants.

It is difficult to know if the students who didn’t perform so well at the start would have performed at a similar level if they were in the app alone or with other people. It is possible that these students learned from observing instead of communicating with the others. This could be the case, as this group completed the tasks given to them much quicker than the other test groups.

The questionnaire given to the respondents were the same questionnaire the archaeology students got last time, shown in section A.5. It consisted of 18 Likert scale questions and one text question. The answers in this questionnaire conformed mostly to what previous respondents had answered. The results from this questionnaire and the one given to the archaeology students were aggregated. An extract of this is shown in figure 7.1.

An interview was also done after testing to measure the overall feeling towards VR technology as a tool for education. The interview questions are presented in section A.7.

The overall response from the interview was positive. Some of the advantages the students indicated were of value when using VR was increased focus as a consequence of fewer distractions, easier for people to be introduced to archaeology, and easier access to field testing wherever you are.

When asked about the potential of VR applications during a situation like the coronavirus the respondents had some new perspectives to add. One of the teacher students had the following to contribute (translated from Norwegian): ”In a VR program you can have different environments like deserts, fields, and tundra. You can experience these environment irrespective of the season or situation of the year you are in“. The student also noted that technologies like VR are going to be more accepted in the future because of the current situation with COVID-19. This comment has been noted before in an earlier survey.

When asked where they thought VR programs fit in to the current specter of theoretical to practical work they noted that VR had practical use within the natural sciences because one can do experiments multiple times without consequence and loss of materials.

Chapter 7

Discussion

7.1 Summary of findings

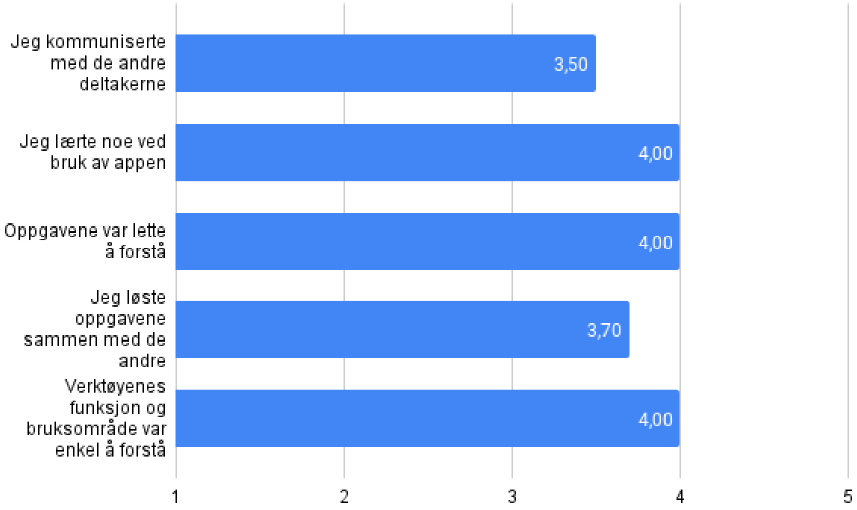

Figure 7.1: Extract from the aggregated result of multiple surveys

Partial aggregation of surveys were done where it made sense to do so, for example in the case where testers had tested the same version of the application with similar questions. When all the aggregated data had been collected together, it became easier to discover and summarize patterns among the users.

During the first, second and third surveys (Section 6.2.1, 6.2.1, and 6.2.1) information about the preferred features and area of use for VR was collected from both teacher students, teachers, and course participants. 28 people of various backgrounds were questioned from three different questionnaires. The surveys indicated that these groups thought that VR would be of most use in a practical lab-exercise, field trips, or class-trip. The features most valued were those that contributed to the ease-of-use of the app, like a simple UI, simple setup, and intuitive controls. 92.7% also thought that VR has the potential to be useful in tasks that require something to be visualized for a better understanding. This finding that VR works best when doing visual tasks matches the findings of Prasolova-Førland [25]. They experienced that collaborative VR works best on tasks which include visual and 3d interaction over technically demanding tasks, like programming.

During the process of development and testing, another pattern that seemed to emerge was the indication that the users who had more fun was also the ones who seemed to learn the most from the application. In the questionnaire, the ones who responded ”Totally agree“ when they were asked if the tasks were fun had an average response of 4.2 to the question of ”I learned something from the app“. The ones who responded less than ”Totally agree“ had an average response of 3.3 to the same question. This pattern was first found in the seventh survey, in section 6.2.3. Preceding research on fun in education[39] also support this hypothesis.

Another pattern was discovered when one considered the progress of the application from the first version to the last. The UX in the early development was not as complete and as easy as it could have been. Problems emerged when the users tried to apply the concepts explained in the tasks to the virtual excavation site. As a consequence, the early users had problems finishing all the tasks or used significantly more time than the users in the later versions. In later versions, it became easier and quicker as more media and UI was added to help out. Effort was also put into making the tools as intuitive and unobtrusive as possible to minimize any hindrances for the users. This aim of making the UI unobtrusive and intuitive is in accordance with the ISO standard of ergonomics of human-system interactions [40].

The collaboration between the participants was also one of the points that was of importance. When interviewing the two experts in archaeology during the last expert meeting (section 6.2.3), they noted that the aspect of collaboration in the VR application is one of the more important lessons that is also useful in real life.

Collaboration was mentioned as one of the criteria they measure students with. Increasing this was therefore of importance when developing. The proof behind this was also hinted at when measuring the average responses of those who responded 4 or above for ”I communicated with the other participants“. Those who responded this had an average response of 4.33 when asked if they felt more comfortable doing practical excavations in the future. Those who responded less than 4 on that question had an average response of 3.25 on this same question. This indicates that adding features that increase collaboration is important when developing any VR archaeology application. These responses were the aggregated results of survey 5, 7, 8, and 9 (Sections 6.2.2 and 6.2.3 to 6.2.3).

Results in figure 7.1 also indicate that VR collaborative learning does have the potential to teach students concepts taught in normal archaeology education. The collaborative aspects of the simulation was lower than expected, but the individuals still learned the tasks and concepts quite well. This indication that VR collaborative learning is effective confirms prior findings done by Souza [24] and Klippel [23]. The aim of creating a simple UX seems to also be achieved with the third and final questions measuring quite high.

Regarding education during COVID-19 the professors and students interviewed were enthusiastic about the possibility of using VR as an education tool during a period like this. Both the students and the professors interviewed commented that they thought VR would become a more accepted tool after COVID-19, as the use of digital tools became more accepted. One of the professors commented that the use of VR would ”Give student a spacious and local experience in Norway’s winter season“. He later explained that this applied to the coronavirus as well, as the coronavirus has approximately the same consequences as winter season has for the archaeology department.

7.2 Project limitations

This thesis has been limited by the time and resources available from the one person developing and researching this project. This single person was responsible for developing, planning, testing, exploring new technologies and solutions to problems, gathering research data, writing the thesis, and all other functions related to this thesis. All of these responsibilities takes a lot of time. As a consequence of these responsibilities, features had to be prioritized according to their importance for the research.

A perhaps not so unique limitation to the research done in this period is the effect the coronavirus has had on testing. Coronavirus measures have varied throughout the year, with periods of mandatory work from home policies. This limited the total access to testers as well as the amount of testers one could test per testing session. This constraint made it difficult to see if the data collected from session to session was affected by environmental factors or actual improvements. Another related limitation has been the home-exam solution employed by NTNU. As a consequence of this, many students have chosen to do their semesters from home instead of in Trondheim, limiting access to the target demographic even more.

The questionnaires has been another limitation. The first of the two major questionnaires targeting archaeology students were slightly varied. This made measuring progress and overall quantitative opinion difficult. Questions were removed from the first to the second questionnaire because it was believed at the time that the removed questions provided no real value to the RQs as the sample size was limited. The idea was to instead do more qualitative data gathering, like interviews and observations. In hindsight, these questions should have been left in the questionnaire, even if they didn't provide as much value.

7.3 Application comparison

In table 7.1 the features of each application reviewed in the related works section are displayed. This showcases where the VR excavation application fits into the context of the other apps. The portable row refers to the portability of the hardware the application is running on. A program is deemed highly portable if it is possible to use the program without cumbersome external tools, like a PC or base stations.

As seen in the table, this app has all the features which are of importance for the research questions. The Historical site feature was not included in this app because it was deemed too technically challenging for one person to do on a weak platform. It is important to note that the VRchaeology and the Pleito VR applications are not available to the public. The features in the table have therefore been extracted from media resources available on them on the internet.

	Collaboration	Excavation simulation	Educational	Historical site	Highly portable	Desktop version
VRchaeology	-	X	X	X	-	?
Pleito VR	X	-	X	X	-	-
Field trips	-	-	X	X	-	-
Norwegian language learning app	X	-	X	-	-	X
This app	X	X	X	-	X	X

Table 7.1: Table displaying the features of the different applications

Compared to the other equivalent applications found in table 7.1 and other equivalent apps out there, the app developed as a part of this thesis fills a space not occupied by any other. As can be seen in the table, the feature distinguishing this app the most from any other is the portability factor, increasing the practical use of the app. Portability is also an essential factor during an event like the coronavirus. This allows a user to easily take the VR headset with them home and set it up. This is difficult with VR hardware dependent on desktop PCs and base stations.

The combination of collaboration and excavation simulation is also something not explored before in VR. This combination allows archaeology students to explore the important collaboration aspect of excavations without doing it in real life. The closest app feature-wise to this app is VRchaeology. The trade-off between the two apps feature-sets is tied to the hardware choice. VRchaeology is able to reconstruct a historical site and render it in VR because of the powerful hardware they are running, doing this on a stand-alone platform like the Quest like this app has done would not have been possible without major drawbacks in performance and graphics.

The Field trips and Pleito VR applications are very similar when comparing just the features in the table. The only difference is the collaborative aspect which

Pleito VR has. These two applications represent most of the VR archaeology applications available on the market, allowing a user to explore a model of an archaeological/historical site using common tools. This functionality of exploring a real model is technically difficult to combine with excavation simulation without a loss of the models fidelity. This can be seen in the VRchaeology application where an archaeological site has been roughly modelled based on a real site. The consequence of this is again the loss in portability, as these models require stronger hardware that is currently difficult to run on standalone headsets.

”This app“ has reached a balance point between the realism of applications like Pleito VR and Field trips, and the excavation simulation of VRchaeology without compromising on portability.

Development of this app has been focused around aspects that have been found to be effective for collaborative educational VR applications in the past. In the background chapter, UI principles like the fishing method of navigation and the grasping method of manipulating has been chosen based on their success in the study at Tongji University [12]. Furthermore, the common principles of VR collaboration like the creation of positive interdependence through a common goal and specific role encouragement through the limitation of excavation tools has been the aim when developing. When combining all these principles and methods the objective was to make the experience as educationally effective as possible.

The combination of all of these methods, principles, and features have shown that remote collaborative learning is possible and in some cases advantageous for archaeological education. The addition of collaboration to this kind of program also adds a much needed dimension not explored before. Collaboration is an important aspect in real-life excavation sites and should not be excluded from educational excavation applications. Collaborating in the virtual world is a rare opportunity for students to learn without any real risk.

7.4 Features not implemented

As is normal for most software engineering projects, not all the planned features make it into the final product. This is the case for this project as well. One of the features that was started, but never finished was the ground layering system. A lot of time was put into developing this system, but because of other priorities, time-constraints, and the limited hardware of the Oculus Quest the feature never made it into the final product.

Another feature that never made it into the final version was the brushing feature. This brush was to be used on excavated rocks to clean them of dirt. Implementing a feature like this would need to involve procedurally editing the texture of the rocks wherever the brush impacted the rock. As the planned feature was of uncertain value beyond adding additional realism it was not specially prioritized.

The last planned feature that never made it into the product was the ability to create and manage multiplayer "rooms" in the lobby of the simulator. This feature would allow the user to create, name, and edit the settings of multiplayer rooms. As the feature had questionable value to the project and added additional complexity for the user it was decided that an easier solution had to be developed. The current solution makes the room creation and joining automatic, making it less complex for a user to get started, but less open to customization.

7.5 Reflections

When looking back at the work done, a lot of time went to developing the application and exploring various ways of solving technical problems. Some of this time should instead have gone to gathering more data and refining the questionnaires. Gathering varied and additional responses would have improved the thesis further by increasing the confidence of the supplied answers to the research questions. Another improvement could have been made at the start of the research. In the beginning the research direction was unclear, deciding on a narrower research direction earlier in the process rather than exploring broad questions would have saved time.

Chapter 8

Conclusion

8.1 Research questions

This section summarizes all the findings gathered and focuses them around the research questions.

> **RQ1:** In the context of COVID-19, can VR be used as a supplement for traditional education?

In the case of archaeology, winter is a time period where no excavation can happen, almost like the current situation with COVID-19. When considering a time period like COVID-19 it is helpful to imagine it as a sort of winter period for an archaeology course.

The findings collected from the tests done with archaeology students indicates that VR technology can be used to support the traditional teaching situation during a situation like COVID-19. Both archaeology students and normal students that have used the application have solved tasks in the app that require them to understand the concepts and skills also required on a real site. Cooperation between testers have also been apparent, this is relevant, as learning to cooperate on an excavation site is one of the areas students are evaluated in. Virtual reality cannot recreate all the nuances of real world excavation and neither has this been explored in this study, we can therefore conclude that VR can only be used in a supportive manner, not as a complete replacement for real practical experience. Interviews of experts in the field also indicate that VR education is best used as a connection between the theoretical and the practical.

Pre-studies done before the development started indicated interest in VR collaborative education beyond archaeological education. Findings in surveys one to three indicate that practical lab-exercises, field trips, and class trips are good targets for supplementing traditional education.

The potential of collaborative VR technologies during the COVID-19 crisis has been displayed not only by this paper, but is also supported by new papers [24] [25] in the field, these were referenced in section 2.5.2. The paper by Souza [24] explored the use of collaborative VR technology for education during the COVID-19 period. Prasolova-Førlands [25] paper did not directly study VR education during the pandemic, but explored the collaborative learning of distributed teams using VR, something especially relevant for this paper. Although the main focus of these papers wasn't COVID-19, they still reference it and show that the use of VR technology during such a period is possible and relevant.

It is important to note that these indications are only valid for the archaeology course, as this has been the main focus of the project. It is still possible that this indication is also valid for other practical courses or other cases, but this study has been mostly limited to archaeology courses.

> **RQ2:** What advantages and disadvantages does a VR remote collaboration education tool provide to archaeological education?

The advantages both found in the findings and the background work are the following: The ability to practice and learn archaeological practices almost anywhere, at any time, even during a pandemic. The possibility of using tools and processes normally not available in real life, either because of cost or availability. Finally, the ability to explore virtual replications of sites not available in real life is a feature unique to VR. The advantage remote collaborative work provide is also substantial, allowing students, teachers, and experts to work and teach together irrespective of their physical distance.

The disadvantages are mostly centered around the software and hardware aspects of the application. The need for the Oculus Quest to practice is apparent, as well as maintaining the software itself. Developing new functionality and maintaining the old ones takes up a lot of time, as shown in the development chapter. Another disadvantage is the case where the developer or user of the application misinterprets a process in the app, creating a false impression of how archaeology really is. This aspect can however be partly mitigated by closely involving experts in the field throughout the development process.

Most of these findings was found in the exploration of related works, in section 2.5.4, as well as the surveys done involving interviews with experts in the field. These findings match some of what is done by Attallah [3] in his paper about wearable technology and education. The advantages of VR technology that he describes is that it can bring a user to a place that is ”...difficult, or sometimes impossible, to access in real-life...“. It continues to say that VR technology enables hands-on, engaged, and interactive participation of students in their learning process. This closely matches the findings in this paper.

> **RQ3:** How should one develop an immersive collaborative VR application for archaeological education?

When developing a VR learning experience, one of the most important points are the transfer-ability of a lesson learned in VR to the real world, and the actual learning outcome. This is also the case for VR archaeology. Increasing these factors should be the aim when developing. These factors has been found to increase by engaging the users and getting the experience as close to a real world experience as possible, while reducing obtrusive elements. Findings indicate that a VR archaeology experience should have focus on the following:

- Collaboration: Testers that communicated more with their fellow participants also indicated that they felt they were more comfortable with doing practical excavation in the future. Collaboration is also an essential part of real life excavations.
- Gamification: Having fun during the experience seemed to be an indicator for learning something in the app.
- An easy and unobtrusive UX: Early testing that was done with a less complete UI made the testers lose focus on their tasks, impairing their ability to learn. Task completion and completion time later increased for the better when improvements had been made to the general UX.

In addition to these points, the portability factor should also be considered when developing a collaborative VR application. This can be important in a situation like COVID-19 when portability of the hardware becomes an issue. It can also increase the general accessibility of the app, increasing its use. The combination of the portability factor and the educational virtual excavation feature has not been explored in any other app before.

These findings closely match those found by Souza [24] in the paper exploring the knowledge transfer and retainment of neuro-anatomy students in collaborative team-based learning. They registered comments that since it has a game-like feel it helps even more in learning. The paper by Bisson [39] also support the idea that fun has a pedagogical benefit for learning.

More information about these findings can be found in section 7.1 and section 7.3.

8.2 Summary

This study has explored VR technology as a potential tool for education in a practical collaborative course. The focus of the paper has been centered around developing an application that replicates the experience of excavating a real dig site. This was also meant to be a tool for education for archaeology students at NTNU. When exploring the preceding research done in this field and the state-of-the-art it was discovered that there had been little preceding work done in the field that combined teaching, virtual reality, and archaeology. The application developed in combination with this thesis was of use when exploring the research questions put forward at the start of the paper. VR as a collaborative teaching tool seems to be a useful tool for archaeology students to use as a connection between the theoretical and the practical skills learned in their field.

8.3 Contributions

As a result of this paper as well as the accompanying application, we have made several contributions.

An application that have helped answer the research questions have been developed. This same app contributes in the teaching of archaeology students at NTNU. The ability to teach archaeology students at NTNU during winter season or situations like COVID-19 has been strengthened. Using this application, the potential of collaborative learning in VR for archaeology students has been explored during the writing of this paper. The advantages and disadvantages of a tool like this has also been considered. At the end of the project, the possibility of replacing physical education with VR education during a situation like COVID-19 was explored. In total, the contributions made in this project can be summarized into the following:

- The development of a new educational VR application for use in the field of archaeology (Chapter 5)
- A better understanding into how one should develop a practical VR application for archaeology students (Chapter 5 and 6)
- Insight into what the advantages and disadvantages VR remote collaboration tools provide to archaeological education (Chapter 6)
- Insight into the potential of VR applications ability to replace real life lessons (Chapter 6)
- Giving archaeology students the unique possibility of performing virtual excavations in a situation like COVID-19.

Most of these contributions are answered as a part of the research questions in section 8.1.

8.4 Future work

As a result of the limitations discussed in section 7.2 some features did not make into the final version of the application. These features were requested by the archaeology expert, but did not make it into the simulator because of the limited time.

There was also some technical aspects that could be improved in a potential next version of the application. For example, the excavation site could be improved using the marching cubes algorithm instead of the standard procedural mesh used. The advantage of using such an algorithm would be increased efficiency, higher detail level, the possibility to change colors of the mesh depending on depth, and a more natural manipulation of the ground. Some of these advantages was requested features by the archaeology department. Using this method, the excavation area could be increased both in size and detail level, improving the experience noticeably.

Other than these missing features, there was also some features suggested from the last interview with two archaeology experts. These were discussed in section 6.2.3, but largely concerns tying the application closer to the curriculum of the archaeology courses at NTNU.

From a research perspective, future work in this area should try to involve a greater sample size. Further research into the possibility of using VR in other parts of the curriculum would be an interesting angle to explore. Expanding the research and the application to encompass a larger part of the archaeological curriculum would better determine if collaborative learning in VR is an adequate platform for archaeological education.

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Appendix A

Questionnaires

Below is a summary of all the questionnaires used when collecting data. The questionnaires have been made into a more readable format for this document. The questionnaires presented in the real world had scales for the Likert scale and were styled.

A.1 First

Questions asking about the users experience or impression of a subject supplies a Likert scale.

Grunnleggende spørsmål

1. Hvor mye tidligere erfaring har du med VR?
2. Gender?

Vurdering av utprøvde app'er

1. Hvilke klimarelaterte VR-app'er har du testet i dag?
2. Hvilken app gjorde sterkest inntrykk på deg?
    - Hvorfor?
3. Hvilken app var minst inspirerende?
    - Hvorfor?

Bruk av VR som erstatning for fysiske læringssituasjoner

1. Har du som følge av korona hatt forelesninger over internett (feks: zoom)?

2. Hva er ditt inntrykk av læringsopplevelsen i disse formatene?
    - Videoforelesning
    - Klasseromsundervisning
    - Selvstudie
    - VR (i dag)
3. I videoforelesninger med større grupper, der flere personer snakker på tvers, hvor vanskelig synes du følgende er?
    - Forstå hvem som snakker
    - Få oppmerksomheten til gruppen
    - Forstå kroppspråk
    - Holde oppmerksomheten til gruppen
    - Følge med på diskusjonen
4. Hvis VR skulle bli brukt i studiehverdagen, hva ville du sagt er de viktigste funksjonene som må med?
    - Muligheten til å skrive notater
    - Personlige avatarer
    - Muligheten til å se andre sine virtuelle hender
    - Manipulering av objekter i f.eks virtuelle labforsøk
    - Muligheten for å bli med i et "rom" uten VR headset, via zoom e.l
5. Noen andre funksjoner som er viktige? (stikkord)
6. I hvilke læringsituasjoner ser du for deg at VR kan bidra mest, når man ikke kan møtes fysisk?
    - ☐ Feltturer
    - ☐ Klasseturer
    - ☐ Praktiske labøvelser
    - ☐ Forelesninger
    - ☐ Møter
    - ☐ Ingen

A.2 Second

This questionnaire was done in collaboration with another study called ”Fremtidens teknologier“. All the questions not relevant for this thesis has been removed for from the questionnaire below for readability.

The questions with bullet points are Likert scale questions, while those with square symbols are markdown questions.

Generelle spørsmål

1. Hadde du noe erfaring med VR/AR teknologier før dette kurset?
2. I dette kurset har jeg...

Spørsmål for videre forskning

1. Hvilke 2 apper synes du hadde den beste totale opplevelsen?
   - ☐ AltspaceVR
   - ☐ Second life
   - ☐ VirBela
   - ☐ Mozilla Hubs
   - ☐ En annen app
2. hva gjorde disse appene bedre enn de andre?
   - ☐ Grafikken
   - ☐ Brukervennlige menyer
   - ☐ Enkelt oppsett
   - ☐ Intuitiv kontroll av figuren
   - ☐ Musikk/Lyd
   - ☐ Enkel redigering av arenaen
   - ☐ Personalisering av avataren
   - ☐ Noe annet
3. Hva annet gjorde de bra?
4. Ranger viktigheten av disse funksjonene for deg i en VR app
   - Grafikken
   - Brukervennlige menyer
   - Enkelt oppsett
   - Intuitiv kontroll av figuren
   - Musikk/Lyd
   - Enkel redigering av arenaen
   - Personalisering av avataren

A.3 Third

This questionnaire was given to a group of teachers. It uses the same format as the questionnaires above.

Grunnleggende spørsmål

1. Har du prøvd VR før?
2. Tror du VR kan bli brukt i undervisning?

Videre spørsmål

1. Hva tenker du om:
    - VR som en erstatning for fysisk tilstedeværelse i sammenheng med korona?
    - At VR kan bidra til det sosiale miljøet til elever som ellers ikke kan møtes fysisk på skolen?
    - Muligheten til å utføre praktiske oppgaver i VR når det ellers ikke er mulig i virkeligheten
2. Hvor viktig er følgende i praktiske oppgaver der elever skal samarbeide
    - Elevens resultat på oppgaven
    - At læreren kan se elevene mens de utfører arbeidet
    - Hvordan en oppgave blir utført
    - Samarbeidet mellom elevene
3. Er det noen praktiske scenarier der du kunne fått bruk for VR?
4. Noen kommentarer til slutt?

A.4 Fourth

This questionnaire was given to a group of archaeology students after they had tried out the second iteration of the application. The bullet points in the questionnaire means a Likert scale was given to the respondent.

Grunnleggende spørsmål

1. Har du prøvd VR før denne dagen?
2. Har du vært ute på et ekte utgravningsfelt før?

Spørsmål om opplevelsen i dag

1. Vurder følgende påstander
    - Realismen i simulatoren er god
    - Jeg lærte noe ved bruk av appen
    - Kontrollene var enkle å forstå
    - Jeg synes oppgavene var vanskelig å forstå
    - Jeg synes det skulle vært andre oppgaver å utføre
    - Verktøyene i bruk på utgravingen var intuitive
    - Jeg kommuniserte med medstudenter i appen
    - Jeg kommuniserte med andre medstudenter for å løse oppgavene våre
2. Vurder følgende påstander
    - Læringsutbytte ved bruk av appen er like bra som i virkeligheten
    - VR arkeologi apper som denne kan være nyttig for studenter
    - VR arkeologi opplæring kan brukes i tillegg til virkelig opplæring
    - VR arkeologi opplæring kan brukes som erstatning for virkelig opplæring når annet ikke er mulig
    - VR kan bidra til det sosiale miljøet til elever som ikke kan møte fysisk
3. Hvis noe, hva lærte du ved bruk av appen?
4. Forslag til forbedring?

A.5 Fifth

This questionnaire was given to a group of archaeology students after they had tried out the third and final iteration of the application. It is largely the same as the one above.

Grunnleggende spørsmål

1. Har du prøvd VR før denne dagen?
2. Har du vært ute på et ekte utgravningsfelt før?

Spørsmål om programmet

1. Vurder følgende uttalelser om tilstedeværelsen din i VR
    - Jeg glemte hvor jeg var (i virkeligheten)
    - Jeg følte meg komfortabel i VR

  - Jeg følte meg tilstede på det virtuelle utgravningsfeltet
  - Jeg følte meg alene på utgravningsfeltet
  - Jeg kommuniserte med de andre deltakerne

2. Vurder følgende uttalelser om læringsopplevelsen
   - Jeg lærte noe ved bruk av appen
   - Jeg lærte noe om koordinatsystemet
   - Jeg ble mer komfortabel med praktisk utgravning
   - Oppgavene var lette å forstå
   - Utførelsen av oppgavene var morsom
   - Jeg løste oppgavene alene
   - Jeg løste oppgavene sammen med de andre
3. Vurder følgende uttalelser om programmets utforming
   - Menyene var enkle å forstå
   - Jeg visste ikke hva jeg skulle gjøre i starten
   - Menyene fungerte sånn jeg forventet
   - Jeg brukte mesteparten av menyene
   - Jeg prøvde både spaden og murskjeen
   - Verktøyenes funksjon og bruksområde var enkel å forstå
4. Har du ellers noen andre kommentarer?

A.6 Interview with Archaeology experts

These questions were asked during an interview with two archaeology professors. The questions acted as guide posts for the interview, but was not the only topic discussed. The interview was recorded for additional data collection.

1. Hvilket potensiale ser dere i VR som et verktøy for læring for arkeologi studenter?
2. I hvilken grad eller hvordan tenker dere VR programmer kan bli brukt ved siden av vanlig pensum?
3. Under en situasjon som coronaviruset eller i vinterstid når det er vanskelig å dra på utgraving hvordan tenker dere at et VR verktøy kan være nyttig?
4. Hvordan ville bruken av VR vært annerledes fra normal studier til en situasjon som covid-19?
5. Hva synes dere om læringsopplevelsen i VR programmet? Er de nåværende oppgavene relevante for pensum?

6. Hvordan vil dere vurdere potensiell praktisk undervisning i VR i forhold til bare teoretisk og ekte praktisk erfaring? Hvor ligger vr erfaring på spekteret?
7. Er det noen andre funksjoner som kunne vært nyttig for praktisk VR? (Større utgravningsfelt, flere analyseverktøy for etter utgravningen, flere oppgaver, modellering av et ekte utgravningsfelt)

A.7 Interview with students

This interview was presented to a group of 4 students testing the application, in survey 9. The questions are mostly the same as the ones asked to the archaeology experts in section A.6. The only difference is the removal of questions only answerable by the experts in the field.

1. Hvilket potensiale ser dere i VR som et verktøy for læring for arkeologi studenter?
2. I hvilken grad eller hvordan tenker dere VR programmer kan bli brukt ved siden av vanlig pensum?
3. Under en situasjon som coronaviruset eller i vinterstid når det er vanskelig å dra på utgraving hvordan tenker dere at et VR verktøy kan være nyttig?
4. Hvordan tenker dere bruken av VR vært annerledes fra normal studier til en situasjon som covid-19?
5. Hvordan vil dere vurdere potensiell praktisk undervisning i VR i forhold til bare teoretisk og ekte praktisk erfaring? Hvor ligger vr erfaring på spekteret?

Appendix B

NSD Form

The following page contains the NSD form used when collecting data in combination with this thesis. People participating in the data collection had to agree to the following document.

Taking part in the research project

” Immersive Technologies for Learning and Training ”

This is an inquiry about participation in a research project where the main purpose is to to explore the potentials and limitations of Immersive Technologies (virtual/mixed/augmented reality, VR/MR/AR) for learning and training in different areas, as a part of master student projects at Innovative Technologies for Learning (IMTEL) VR lab. To conduct this research, we will need to investigate the development and use of immersive technologies for learning and training in various contexts, including learning of language and mathematics, virtual field trips, remote learning in COVID-19 context, visualization of climate change, immersive visualization of lab experiments, workplace training, visualization of medical procedures and anatomy and other projects. In this form we will give you information about the purpose of the project and what your participation will involve.

Purpose of the project

To conduct this research, we will need to analyze the use immersive technologies for learning and training in various contexts, including learning of language and mathematics, virtual field trips, remote learning in COVID-19 context, visualization of climate change, immersive visualization of lab experiments, workplace training, visualization of medical procedures and anatomy and other projects. The goal is to develop innovative learning methods and tools using immersive technologies.

Who is responsible for the research project?

NTNU, Department of Education and Lifelong learning is the institution responsible for the project.

Why are you being asked to participate?

You are asked to participate because you are a potential user of educational applications developed as a part of this project and have visited our lab/expressed interest in immersive technologies. Your feedback is important for develop innovative learning methods and tools.

What does participation involve for you?

You will be ask to test immersive applications for learning and training purposes and then give feedbacks in the form of questionnaires and interviews/group interviews.

Participation is voluntary

Participation in the project is voluntary. If you chose to participate, you can withdraw your consent at any time without giving a reason. All information about you will then be made anonymous. There will be no negative consequences for you if you chose not to participate or later decide to withdraw.

Your personal privacy – how we will store and use your personal data

We will only use your personal data for the purpose(s) specified in this information letter. We will process your personal data confidentially and in accordance with data protection legislation (the General Data Protection Regulation and Personal Data Act). Any data that can be traced to individual participants will be kept confidential and anonymized before being used for research purposes. Parts of the sound recordings will be transcribed (written down) and stored electronically. All source data will be handled and stored in accordance with the existing regulations by NTNU as the responsible institution and only persons associated with the project (IMTEL VR lab research personnel and master students) will have access to them.

What will happen to your personal data at the end of the research project?
The project is scheduled to end 31.12.2021. All data will be anonymized at the end of the project, e.g. audio and video will be deleted when transcripts and analysis of data are completed, except for selected video and photo material to be used for research purpose. These and anonymized recordings from the inside of the virtual environments may be used for demonstrations in research context in such a way that no information will be linked to individuals. Scientific reports and presentations from this study might contain recordings from the VR/MR/AR sessions, questionnaire results, anonymized photos/videos from the sessions and anonymized citations from the interviews.

Your rights
So long as you can be identified in the collected data, you have the right to:

- access the personal data that is being processed about you
- request that your personal data is deleted
- request that incorrect personal data about you is corrected/rectified
- receive a copy of your personal data (data portability), and
- send a complaint to the Data Protection Officer or The Norwegian Data Protection Authority regarding the processing of your personal data

What gives us the right to process your personal data?
We will process your personal data based on your consent.

Based on an agreement with NTNU, NSD – The Norwegian Centre for Research Data AS has assessed that the processing of personal data in this project is in accordance with data protection legislation.

Where can I find out more?
If you have questions about the project, or want to exercise your rights, contact:

- Ekaterina Prasolova-Førland (Department of Education and Lifelong Learning, NTNU)
- phone: +47 99 44 08 61, email: ekaterip@ntnu.no
- NSD – The Norwegian Centre for Research Data AS, by email: (personverntjenester@nsd.no) or by telephone: +47 55 58 21 17.

Consent form

I have received and understood information about the project **Immersive Technologies for Learning and Training** and have been given the opportunity to ask questions. I hereby declare my consent that my data in relation to Immersive Technologies for Learning and Training may be stored, documented and used for research and educational purposes as described above. I give consent for my personal data to be processed until the end date of the project, approx. 31.12.2021

(Signed by participant, date)

Filip Hagen

NTNU
Norwegian University of
Science and Technology