

Sølve Robert Bø Hunvik

# Using Virtual Reality for Artificial Intelligence Education

Master's thesis in Informatics

Supervisor: Frank Lindseth

July 2020



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



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# Preface

This thesis is Sølve Robert Bø Hunvik's final project for his Master of Science in Informatics at the Norwegian University of Science and Technology, with a specialization in Software Engineering. The goal of the thesis was to explore how virtual reality can be utilized as a tool for learning in artificial intelligence education. Artificial intelligence courses often build on complex mathematical theory, which Sølve has sometimes experienced as intimidating. His personal motivation for the project was to see if being immersed in a virtual world can make the theory feel more engaging and intuitive.

The target group of the VR application developed for the project is students who are getting into introductory courses of deep learning or are generally interested in artificial intelligence. The thesis is mainly intended for people looking to apply virtual reality in artificial intelligence and computer science topics. However, the concepts applied in the project should also be relevant to other STEM courses. This report will cover the necessary details for being able to continue working on the overall project.

Trondheim, July 14, 2020  
Sølve Robert Bø Hunvik

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# Acknowledgment

I would like to thank my supervisor, Frank Lindseth, for his valuable guidance and feedback throughout the project. He also provided the necessary tools and equipment at the XR Lab. Also, I want to thank Håvard Snarby for letting me participate in his project. Evaluating his application in Phase 1 gave me valuable insight for the rest of the project and his help and tips got me up to pace with VR development at an earlier stage. I would like to thank the IMTEL network staff giving useful tips, letting me participate in seminars, and for letting me distribute the VR application in the network to conduct user tests.

Furthermore, I would like to thank the people from NTNU's OpenAI and DART research groups, the students in the IMTEL network, Reddit communities, and everyone else who participated in the evaluation. Their valuable feedback made it possible to realize evaluation during the difficult times of the global pandemic. Also, I would like to thank the people of the VRTK community who helped me solve complex problems where no documentation was available.

I wish to show my gratitude to all my friends and classmates for making these five years of study the best years of my life.

Finally, I wish to express my deepest gratitude to my family - Astrid, Arne, Hanne Martine, and Kristoffer. They have always kept me going and inspired me to pursue my interests and ambitions. I would not have been able to accomplish this without their support and encouragement.

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# Abstract

In recent years, the need for artificial intelligence (AI) competence has increased at a high rate. Universities and companies worldwide are attempting to meet the need for competence. Since the release of the first consumer virtual reality (VR) headsets in 2016, VR has become a bigger topic than ever in education. However, the field is still young, and much research is needed to find the best ways to apply VR in education.

This thesis explored how VR can be used in AI education. The goal was to develop a VR application that gives an engaging introduction to deep learning and neural networks to see what students think about using the tool for learning. The project consisted of two phases of research. In Phase 1, another VR application from the overall project was user-tested by 12 students in a deep learning course. We revealed that the project had potential, but that much work was needed to justify the use of VR. A new concept was defined for Phase 2, based on the results and the literature study. The new concept was to apply educational escape room elements, as an attempt to let students engagingly learn the curriculum, by doing 3D-puzzles, calculations, and quizzes based on the course-material. The curriculum's topics were split into separate rooms to give intuitive progress. A VR application was developed for the standalone Oculus Quest, to make a more accessible tool for students and efficiently conduct user-tests. The 5-minute video in [this link](#) covers the concept and majority of contents of the application. The prototype was evaluated in two alternative ways online, due to the global pandemic of 2020. 15 people tested the application and responded to a questionnaire. 26 people responded to a questionnaire after watching a video.

The results showed that people were very interested in the concept, and it could potentially also be beneficial in other courses that require a visual understanding, such as STEM-courses. The users were highly interested in 3D-visualizations, like the visualization of gradient descent and neural networks. Also, the participants showed interest in multiple tasks. In conclusion, the main advantages of using a VR application in this context is to apply interactive 3D-visualizations that are challenging to experience by other means, and encourage students to "learn-by-doing". This is one of the first research projects exploring the use of room-scale standalone VR in education. It has shown great potential since the tool can be made accessible for students more easily, even though the software requires higher optimization efforts, compared to tethered devices. One potential use case of the final application is to apply it as a supplementary tool, that gives students an introduction to new topics within AI. Then the students can proceed with traditional learning methods to understand the curriculum entirely.

**Keywords:** *Virtual Reality, Immersive Learning, Standalone Virtual Reality, Mobile Learning, Oculus Quest, Artificial Intelligence, Deep Learning, Educational Escape Room.*

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# Samandrag

I dei siste åra har etterspurnaden etter kompetanse innan kunstig intelligens (Artificial Intelligence, AI) auka raskt. Universitet og bedrifter verda rundt prøvar å dekke kompetansebehovet. Sidan dei første virtuelle verkelegheit (Virtual Reality, VR) hovudsetta kom til forbrukarar i 2016, har VR vore eit stort tema innan utdanning. Feltet er enno ungt, og det er behov for mykje forskning for å finne dei beste måtane å bruke VR i utdanning.

Denne avhandlinga har utforska korleis VR kan brukast i AI-utdanning. Målet var å utvikle ein VR-applikasjon som gjer ein engasjerande introduksjon til djup læring (deep learning) og nevrane nettverk (neural networks), for å sjå kva studentar synast om å bruke eit slikt verktøy til læring. Prosjektet bestod av to fasar med forskning. I Fase 1, vart ein annan VR-applikasjon frå det overordna prosjektet brukartesta på 12 studentar frå eit fag om djup læring. Vi avslørte at prosjektet hadde potensiale, men at mykje arbeid måtte gjerast for å rettferdiggjere bruken av VR. Eit nytt konsept vart definert for Fase 2, basert på resultat frå brukartesting og litteraturstudiet. Det nye konseptet gjekk ut på å bruke utdannings-”escape room” element, for å la studentar lære pensum på ein engasjerande måte ved å gjere 3D-puslespel, utrekningar og quiz basert på pensum. Dei ulike tema i pensum vart delt inn i separate rom for å gje studentane intuitiv progresjon gjennom pensum. Ein VR-applikasjon vart utvikla til det frittstående VR-hovudsettet Oculus Quest, for å lage eit lett tilgjengeleg verktøy for studentar, og for å kunne effektivt gjennomføre brukartestar. Den 5 minutt lange videoen i [denne lenkja](#) dekkjer konseptet og mesteparten av innhaldet i applikasjonen. På grunn av den globale pandemien som pågjekk, vart prototypen evaluert på to alternative måtar på internett. 15 personar testa applikasjonen og svarta på eit spørjeskjema. 26 personar svarta også på eit spørjeskjema etter dei hadde sett ein video.

Resultata tilsa at brukarane var veldig interesserte i konseptet, som potensielt også kan vere nyttig i andre fag som krev ei visuell forståing av pensum, slik som vitenskaplege fag. Deltakarane viste stor interesse for 3D-visualiseringar slik som for ”gradient descent” og nevrane nettverk. I tillegg viste deltakarane interesse i fleire av oppgåvene. Det blei konkludert at hovudfordelane med å bruke VR i denne samanhengen var å bruke interaktive 3D-visualiseringar, og å oppfordre studentar til å ”lære av å gjere”. Dette prosjektet er eit av dei første forskingsprosjekta som har utforska bruken av eit frittstående rom-skala VR-hovudsett i utdanning. Verktøyet har vist seg å ha stort potensiale, sidan det kan gjerast lettare tilgjengeleg for studentar, sjølv om det krevst meir arbeid for å optimalisere programvare, samanlikna med kabla hovudsett. Eit potensielt bruksområde for den endelege applikasjonen kan vere som eit tilleggsverktøy, der studentar får ein introduksjon i nye tema innan AI. Deretter kan dei forsetje med tradisjonelle læringsmetodar for å få ei fullstendig forståing av pensum.

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# Abbreviations

VR	=	Virtual Reality
HMD	=	Head-mounted Display
AR	=	Augmented Reality
XR	=	Mixed Reality
FOV	=	Field of View
FPS	=	Frames Per Second
DoF	=	Degrees of Freedom
SDK	=	Software Development Kit
API	=	Application Programming Interface
VRTK	=	Virtual Reality Toolkit
AI	=	Artificial Intelligence
DL	=	Deep Learning
NN	=	Neural Network
SUS	=	System Usability Scale
STEM	=	Science, Technology, Engineering and Mathematics

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# Chapter 1

## Introduction

### 1.1 Project Motivation

#### A Virtual University

Universities apply video lectures, hands-on projects for assignments, supportive software tools, and more for teaching the curriculum. However, universities are mainly applying traditional teaching methods, and new alternative methods are rarely introduced. Google has released the Machine Learning Crash Course [7], which efficiently teaches the theory by putting students through hands-on projects and let them play with interactive visualizations. Plenty of similar interactive courses exists for teaching other topics as well. Furthermore, the difficult times of the global pandemic in 2020 have shown that having good technological tools for education is more important than ever.

#### Artificial Intelligence

The need for competence in artificial intelligence (AI) has increased at a high rate around the world in recent years. That is due to discoveries of new successful applications of AI and advancements in hardware and cloud solutions. AI is generating large amounts of value to the global economy. The machine learning market is estimated to expand by a CAGR (Compound Annual Growth Rate) of 43.8% from the USD 6.9 billion in 2018 to USD 96.7 billion in 2025 [8]. This does not only show that AI is a valuable industry, but that the demand for competence will keep increasing in the upcoming years.

In August 2018, Digital21 published a report stating that AI was one of four important strategic areas that Norway should invest more in[9]. With a growing interest in AI in multiple sectors and from the government's agencies itself, it was suggested that the government should release its national strategy. After a comprehensive work, the strategy was released in January 2020 [10]. Norway has a goal of being forefront in AI education, research, and innovation, which means that the need for competence is higher than ever. It

is part of the digital transformation, which means that universities need to focus more on educating students on the topic. To fully meet the demand, companies need to put employees through lifelong learning programs. AI is currently being taught through traditional methods like lectures, assignments, and hands-on projects.

Knowing that AI will affect our future, a course called "*Elements of AI*" [11] was released by the Finnish company Reaktor University of Helsinki. Their goal is to educate 1% of the European citizens on the basics of the topic within 2021. Companies worldwide are encouraging their employees to take the course.

### **Virtual Reality**

Since the release of Oculus Rift and HTC Vive in 2016, virtual reality (VR) has shown its power to create unique gaming experiences. It has also proven to be a useful and promising tool in other industries as well. Examples of industries are health-care, construction, manufacturing, and education [12]. In 2015, VR was at the peak of the Gartner Hype Cycle [1], and it kept moving against the stage of maturation. In 2018, VR was no longer placed on the Gartner Hype Cycle, which meant that VR was no longer an emerging technology, but had reached the stage of maturation [13]. The technology has been seen as something that will revolutionize the way people interact, in similar ways to the internet, smartphones, and smartwatches.

VR has not yet had a mainstream breakthrough, due to high prices, comfort issues, skepticism, and lower amounts of top-tier software. However, innovative technological advancements make VR more promising than ever. Oculus Quest was released in May 2019. It is a moderately priced standalone device that makes highly immersive experiences accessible to a larger number of people. Previous VR headsets required a powerful and expensive computer and going through a cumbersome setup of cables and tracking sensors. The device did not require any of this, which is one of the main reasons it became very popular. Seeing that the device can also be used as a tethered device, has made the media write about a promising future for VR [14].

### **Virtual Reality in Education**

VR has shown some promising results in education since the immersive learning methods have given positive impacts on learning outcome and retention of information. One example is a study that compared people's ability to remember faces using a 2D monitor and VR [15]. The perception of presence in the virtual world showed to give a significant difference in the users' ability to recall information. VR opens for possibilities for interactions and visualization of concepts that would otherwise be impossible or highly demanding to recreate.

This thesis will explore how VR can be used as an engaging tool for learning in AI education, to meet the demand for competence.



## 1.2 Problem Description

Students find certain topics within artificial intelligence challenging to understand through traditional learning methods, and often seek interactive and visual ways of learning. Due to the high demand for AI competence, this thesis will explore how VR can be utilized to learn the topic in an engaging, interactive, and immersive way. The subject within AI for the project will be deep learning. Through this project, another VR application that has been developed for the overall project will be evaluated. The author will then use the insights gained from the evaluation and his literature study to design and implement a new application. The new application will also be evaluated to get insight into what can make VR a valuable tool in this context.

The target audience will mainly be students in introductory deep learning courses. In some courses, students are expected to have prior knowledge of deep learning. Since some students lack this knowledge when signing up for the course, the application could be used to get up to pace with the other students. Also, the tool could be made accessible to others interested in AI.

## 1.3 Goal and Research Questions

This master's thesis aims to figure out if VR can be used to teach AI in an engaging and immersive way and to see what students think about the learning method. Also, the thesis will try to address how the findings are relevant to other STEM courses.

A main research question was defined with four sub-questions. The first three sub-questions will be used to respond to the main research question. The last one will have a broader perspective, looking at how the research outcome can be applied in other STEM-courses.

**RQ: Can virtual reality be utilized as a tool for learning in artificial intelligence education?**

- **RQ1:** How can virtual reality be used in artificial intelligence education?
- **RQ2:** Can a virtual reality application be implemented to give an engaging introduction to deep learning?
- **RQ3:** What do students think about using such an application as a supplement to traditional learning methods?
- **RQ4:** Are the findings relevant for other STEM courses?

## 1.4 Contributions

Few previous projects have explored the use of VR in computer science education. No previous studies were found where VR has been applied in AI education. However, some previous master thesis projects at the Norwegian University of Science and Technology's XR lab have explored how VR can be applied in an algorithm and data structures course,

where students do "learning-by-doing" tasks [16]. The project had limited results considering evaluation, but the VR application was met with interest from users.

Through this project, another VR application that had been developed for the overall project was evaluated. We revealed that the project had potential. A new prototype application was developed based on the evaluation and the literature study, introducing escape room concepts. Educational escape rooms are an emerging field, and this thesis is one of the first projects to explore the exclusive use of these concepts in VR. The application was developed for the Oculus Quest, making this thesis one of the first projects exploring room-scale standalone VR in education. The application is documented through this report and is available in a public repository on Github [17]. Videos were made to convey the application's concepts and contents, and the application has been built to work on Oculus Quest, Rift, and Rift S. The videos and download link for the application can be found in section 5.2. The application was evaluated online through user tests and video evaluation.

An extended abstract was submitted to the "International Workshop on Higher Education Learning Methodologies and Technologies Online", HELMeTO 2020. The extended abstract was accepted on July 12, 2020. The revised version of the extended abstract can be found in Appendix section A.1. The final version of the draft proceeding shown in Appendix section A.2 will be submitted to the HELMeTO 2020 workshop.

## 1.5 Thesis Structure

### **Chapter 2 - Background and Related Work**

The chapter goes into the theory of VR, learning, and deep learning and the technologies used for VR and game development. Then, the chapter gives an overview of the previous works related to the project.

### **Chapter 3 - Methodology**

The chapter describes the research and development methodologies used, how and why the project was divided into two phases, the technology choices made for the Phase 2 application, and methods used for evaluation.

### **Chapter 4 - Implementation**

This chapter introduces the new concept for Phase 2 that was defined based on the results of Phase 1 and the literature study. Then, the new application's requirements are presented, and the chapter goes into detail on design and implementation.

### **Chapter 5 - Results**

The chapter gives an overview of the application used for evaluation in Phase 1 and the new application developed through Phase 2. The chapter also presents results from the evaluation in both phases.

### **Chapter 6 - Discussion**

In this chapter, the results from the evaluation of both phases will be analyzed and discussed. Then, the research questions will be addressed, and the author will reflect on the work.

### **Chapter 7 - Conclusion and Future Work**

The last chapter will give a conclusion on the thesis and discuss potential future work.



# Chapter 2

## Background and Related Work

This chapter gives an overview of the relevant background theory, technology and related work.

### 2.1 Theory

This section will first discuss the history of virtual reality (VR) and what makes VR promising in 2019-2020. Then, some research on what makes educational games and VR beneficial for learning will be presented. Since VR is quite different from other technological products, some design considerations will be discussed. In the end, the section will briefly present the theory behind deep learning and neural networks.

#### 2.1.1 Virtual Reality

Virtual Reality (VR) is a type of technology used to immerse users into experiencing presence in another world, where the user can interact with a virtual environment. Two main elements are essential, to give users this kind of experience. The first one is to display three-dimensional images, where the virtual objects displayed have about the same size as a life-sized object. The user sees this from within a Head-Mounted Display (HMD). The second element is to track the user's movement and reproduce this in the virtual world [18].

This section seeks to give a brief overview of the history of VR and discuss why VR is a hot topic at the time of this thesis. For a more technical overview of the VR devices available, read section 2.2.



(a) Stereoscope from 1897 [20]



(b) The 2019 Oculus Quest

**Figure 2.1:** VR history

## History

In the 1800s, the stereoscope was invented. The person using the stereoscope looks at two photographs that are taken from slightly different angles (see Figure 2.1a). The eyes are separated in the device, making each eye look at one of the photographs. The photograph is perceived as if it was three-dimensional [19]. The discovery of how vision functions, laid the foundation of how virtual reality works today.

In 1968, the first HMD was created. The device displayed simple wireframe rooms and objects that changed perspective as the user turned his head. In many subsequent years after the first HMD was released, different companies and universities developed devices that enabled motion-tracking for head, body, and hands. In the 90s, VR was introduced in the gaming industry by SEGA and Nintendo. Due to low technical specifications that made users experience severe discomfort, and the low amount of available software, the devices were discontinued, and faced commercial failure. VR was not a mainstream topic for many years. However, research in the field kept going.

In 2012 the idea of using HMDs for immersive experiences was brought back to life. Oculus Rift was presented in a Kickstarter campaign, promising developer kit HMDs with high-resolution displays and a wide field of view with low-latency head-tracking. The idea was to connect the HMD to a PC and take advantage of the high specifications to fulfill their promises. The Kickstarter campaign was fully funded within only a few hours [21]. In 2014, Facebook saw the potential of VR and purchased the Oculus VR company for US\$ 2 Bn [22]. Facebook's purchase of the company was a significant turning point for the VR industry since multiple other companies followed. Google, Samsung, HTC, and Playstation announced that they were planning to release VR technology. Two development kits were shipped to backers of the Kickstarter campaign from 2013-2014. The development kits were intended for developers to create software for the official release of the Oculus Rift. In 2016, Oculus Rift and HTC Vive were officially released to the public, primarily as gaming devices. The same year, a large number of companies started developing software for VR.

## What makes VR promising in 2019-2020

Since the launch of the HMDs in 2016, the media's viewpoints on the technology went from something that could change the way we use technology forever, to be mainly a niche market for gamers [23]. The high price of the devices and requirement of having a powerful PC has made the technology less accessible for the masses, and therefore also difficult to have a mainstream breakthrough. Other reasons why VR has not had a mainstream breakthrough are due to its discomfort and usability challenges. Also, VR was possibly overshadowed by the hype of AR (Augmented Reality) games, such as "Pokemon Go", which was easily accessible to anyone through the smartphone. Also, with the lack of users, it is hard for developers to release AAA titled games [24], even though this is a necessity for consumers to make the technology reach mass adoption.

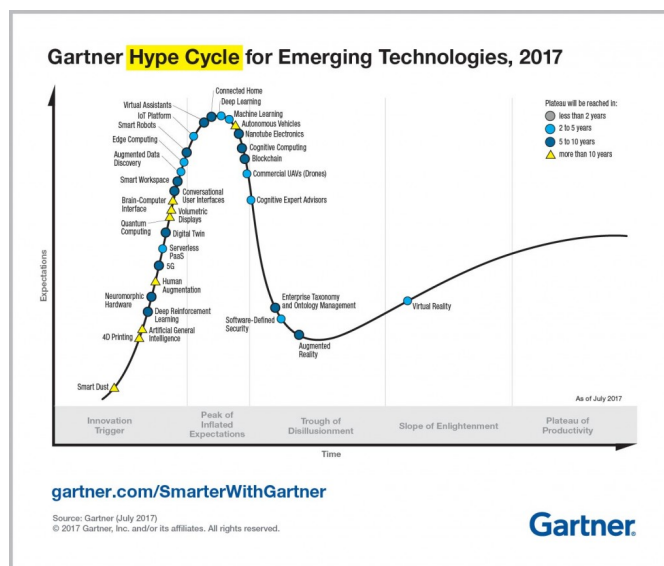


Figure 2.2: Gartner Hype Cycle 2017 [1]

Despite the consumer and developer skepticism, the industry is expected to grow to US\$ 120.5 Bn by 2026, compared to 2018's US\$ 7.3 Bn [25]. According to Gartner Hype Cycle [1], the technology was at its best stage in 2015. Since then, VR has moved more and more against a stage of maturation until 2017, as shown in Figure 2.2. Since 2018, the technology has disappeared from the Hype Cycle. According to Gartner, this meant that the technology reached the stage of maturation, and is no longer an emerging technology [13]. This is due to the variety of sectors where VR has been applied successfully. The major VR stakeholders focus heavily on gaming, but the technology has potential in many other sectors, such as health care, automotive, construction, education, and more [12]. A large amount of research is being put into how VR technology can best be used.

Furthermore, there have been some technological advancements in the industry that makes everything more promising. HMDs started supporting tracking through embedded cam-

eras, instead of using external sensors, making set up easier. After the release of Oculus Quest (see Figure 2.1b) in 2019, a moderately priced device, with no requirement of a powerful computer and a cumbersome setup of cables and tracking sensors, made VR more accessible to consumers. The device also proved to give a highly immersive experience, even on weaker hardware. The device has been admired, and the media is talking about standalone as the way to go. Seeing that the device can also be used as a tethered device using Oculus Link since November 2019, it is still exciting to see if or when VR will have a mainstream breakthrough.

### 2.1.2 Learning

A variety of studies have been conducted, focusing on the effects of using 3D visualization and virtual environments for learning. This section focuses on the effects of using visualizations and games for learning. Then, the section will describe the four main aspects that make VR technology a promising tool for education.

#### Learning Styles

Felder and Silverman conducted a study where they explored different styles of learning and teaching [26]. In their study, they classified different groups of methods that students prefer for receiving and processing information. Many engineering students have more "visual, sensing, inductive and active ways of learning", which makes exclusive use of the traditional teaching techniques inadequate. Their study suggests that professors should balance the styles used to teach the curriculum. Some students are more dependent than others on having graphical visualizations and more hands-on inductive ways of learning. New learning methods may also come with the disadvantage of being perceived as time-consuming for some students, compared to the traditional methods. The most effective and useful methods can be discovered over time by attempting to find new ways and applying technology through trial-and-failure.

#### Educational Games

Game-based learning is a large field. Therefore, this section will focus on the core elements that make games effective for learning. An effective game for learning needs to combine good game design and good pedagogy. The book *Games, learning and assessment* defines seven core elements of a well-designed educational game [27]. These are listed in Table 2.1.

#### VR in Education

VR has shown positive results for learning in a variety of ways. A study from 2016 about trends of using virtual technologies in education [28] describes four main aspects that makes VR beneficial for learning:

- Being immersed in a virtual world where the user can study 3D models differently enhances their learning experience through increased motivation and engagement.



<b>Element</b>	<b>Description</b>
<b>Interactive problem-solving</b>	Players needs to be able to interact with the game by solving a series of problems throughout the game.
<b>Specific goals/rules</b>	The player needs to follow goals and rules to understand how to progress.
<b>Adaptive challenges</b>	The game should be designed to have a balanced difficulty throughout the experience.
<b>Control</b>	The player should feel in control of the gameplay, environment, and the learning experience.
<b>Ongoing feedback</b>	Players needs to be given adequate feedback to measure performance and progression.
<b>Uncertainty</b>	The player should not be able to predict what will happen at any time. With some uncertainty, the player will be kept motivated throughout the experience.
<b>Sensory stimuli</b>	The combination of graphical work, audio, and narrative needs to somewhat please the player.

**Table 2.1:** The seven elements of a well-designed educational game

- The students' ability to interact with and manipulate 3D objects and get feedback improves learning.
- Technological advancements is making VR more affordable and accessible.
- The technology itself with new systems for haptics gives a new level of immersion so that the user can experience environments that would be impossible or very difficult otherwise.

### 2.1.3 Designing for VR

In VR, the user is fully immersed in a virtual world, making it important to mitigate any potential type of discomfort. Intuitive interfaces are important in every IT system, but in VR, the user does not have anything else than what is present to him in the virtual world to help him out. Jerald's book *"The VR book: Human-centered design for virtual reality"* [29] is a comprehensive work on guidelines for VR development. Jerald states:

*"Perhaps the most important part of VR interaction is the person doing the interacting."*

The book shows the importance of following a human-centered design approach. The subsections below give a short introduction to some important considerations that are crucial for VR development.

### Discomfort

When developing for VR, a difficult but crucial design consideration is **VR sickness**. Jerold [29, part III] uses VR sickness as an umbrella term for all discomfort experienced through the use of VR. Examples of discomfort that a user can experience are motion sickness, eye strain, seizures, aftereffects, hardware challenges, and latency. There are multiple theories of why VR users experience **motion sickness**. The most well-known theory is that the user experiences discomfort, due to sensory conflicts between the virtual and physical world, that send confusing messages to the brain [29, chap. 12]. For example, this happens when the user sees that he is moving in VR, even if he is standing completely still in the real world.

All types of discomfort the user can experience are important to consider, but motion sickness is the most common and severe type of discomfort. Designers and developers can make many important decisions that minimize experienced motion sickness by the way users interact and move in the application. Most of the other types of discomfort are minimized by fulfilling performance requirements laid out by HMD vendors.

### Design principles

Creating intuitive interfaces is important in VR development. The user should easily be able to understand the concepts presented in an application. To achieve this, it is smart to use interaction metaphors that reflect the real world, so that the user easily develop a mental model, that suits the intentions of the developers [29, chap. 25]. It is useful to follow Don Norman’s principles of interaction design [30], to create intuitive interactions. Table 2.2 shows some of the relevant principles for VR.

<b>Principle</b>	<b>Description</b>
<b>Affordance</b>	The clue an object gives the user on how to use it. Good affordance, means that it is easy to know how to use an object.
<b>Signifier</b>	An indicator placed in the environment to tell the user how something should be used.
<b>Constraint</b>	The communicated limitation of an interaction.
<b>Feedback</b>	Any visual, haptic or auditory indicator telling the user the results of an action.
<b>Mapping</b>	The relationship between controls and their effects on the object or environment.
<b>Consistency</b>	This means having similar elements for doing similar tasks. For VR this is not only relevant within one application, but also between the different applications.

**Table 2.2:** Don Norman’s design principles

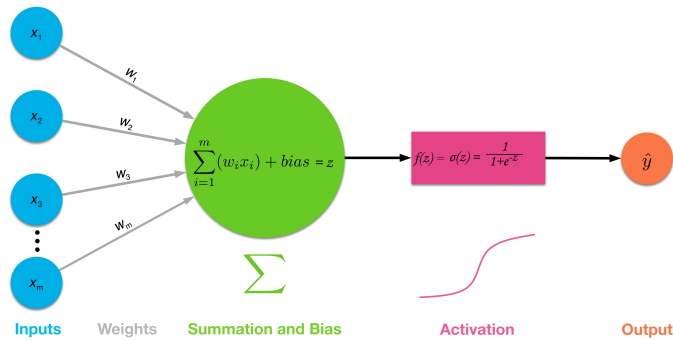
When developing user interfaces, it is important to follow Gestalt principles of visual perception in mind [31] for the grouping of objects. For VR, the principles are especially relevant for any user interfaces where text, images, or colors are used. Ex. the game menu.

## 2.1.4 Deep Learning

The main sources of inspiration used for teaching deep learning and neural networks in the project's application were Michael Nielsen's book on the topic [32] and the 3Blue1Brown series on YouTube [6]. This section gives a short introduction to the main topics that will be covered in this project's VR application.

### Neural Networks

Neural networks are used in deep learning to make complicated decisions, such as recognizing images, speech, audio, and more.



**Figure 2.3:** A neuron from a neural network [2]

A neural network (NN), consists of neurons that are arranged in multiple layers. Each neuron has one or more *inputs*, which can either be the training input to the network or the output of a neuron in the previous layer. Each input is *weighted*, and a *bias* is added to calculate the *weighted sum*. Then, an *activation function*, such as the *sigmoid function*, is applied to the weighted sum to make the neuron output a value between 0 and 1.

### Cost functions

The neural network is given a cost value to evaluate how well it performed on some training data. Based on the NN's predicted output and the expected output for some training example, the cost is calculated using some cost function. The value is further used to improve the neural network's performance by adjusting the network's weights and biases step-by-step.

### Gradient Descent

Gradient descent is an algorithm used for minimizing the output of the cost function. When the partial derivatives for every weight and bias with respect to cost have been found, gradient descent is iteratively used to find a local, or more hopefully, the global minimum of the cost function.

## Backpropagation

Backpropagation is an efficient algorithm used for finding the partial derivatives of each weight and bias in a neural network with respect to the cost [32, chap. 2]. After the cost has been found, the chain rule is applied by propagating backward through the network to find all partial derivatives.

## 2.2 Technology

This section will first describe the technical specifications that are important to consider before starting with VR development and then present the most popular VR headsets by the major manufacturers. Then, the game engines and SDKs used for development will be presented.

### 2.2.1 Virtual Reality Headset Specifications

This section describes some of the specifications and functionalities found in VR headsets, relevant to the choice of HMD for this project.

#### Groups of HMDs

There are three main categories of VR headsets:

1. **Tethered HMDs** are the most powerful and performance demanding. These are dependent on a computer's high technical specifications for doing the heavy computations, needed to deliver top-tier graphics with a high update frequency.
2. **Standalone HMDs** are devices where the headset itself has a built-in computer to handle computations. These headsets come with built-in sensors for tracking and controllers. The HMDs are less powerful than the tethered ones. They are currently increasing in popularity, due to more and more powerful devices and better optimization techniques. The devices give an immersive experience without the need of cables.
3. **Mobile HMDs** are devices where the user's mobile phone is inserted and used to experience VR. This is a cheap way to experience VR, but the experience is much less immersive, due to the lack of computational power, sensors and controllers. The group was therefore not considered for this project.

#### Degrees of Freedom

One thing that distinguishes the VR headsets, is how the user's movement is tracked. In total there are six "degrees of freedom" (DoF), in which a person can be tracked. Every VR application tracks rotation around the x, y and z axis, allowing you to look left and right, up and down as well as rotating your head sideways. This type of tracking gives 3DoF. In addition to this, 6DoF is achieved by tracking translational movement along the axes, letting you walk around in a virtual environment, since it tracks walking forward,

backward, to the left, to the right, as well as up and down [33]. To give the most immersive experience, it is not only important to enable 6DoF for the HMD, but also for the controllers.

### **Tracking Sensors**

Tethered HMDs are often dependent on external sensors, connected to a PC. When two or more sensors are placed around the room to enable 6DoF, it is known as **outside-in tracking**. Companies manufacturing VR headsets have recently been replacing this with **inside-out tracking**, where the HMD uses cameras on the surface of the device to track the user.

### **Field of View**

The human field of view (FOV) is built up of a horizontal monocular FOV on each eye with an angle ranging from 170° to 175°. This angle goes from the nose to the side of the head. Combined, the FOV given from both eyes is 200° to 220°. The overlapping part of the FOV on each of the human eyes is about 114°, and this is the part of the FOV where things are perceived in 3D. This part of the FOV is called the stereoscopic FOV [34]. A wide field of view can increase the feeling of immersion, but most of the VR headset FOVs range around 110°. Every VR HMD uses the principle of the stereoscope to enable the user's vision to perceive what is displayed in 3D, as mentioned in section 2.1.1.

### **Refresh rate**

The refresh rate is how often the device's screen updates the image displayed. For a high refresh rate to be comfortable, it is dependent of a high framerate delivered by the software executed. 60 frames per second (FPS) is normally considered to be playable, but to reduce motion sickness, it is important that the device tracks motion in the same or a higher refresh rate than what the human mind perceives. The high-tier tethered VR-devices focus on having a high refresh rate of 80-90 Hz which is generally considered very comfortable, while the standalone devices refresh rates ranges from 70 Hz to 90 Hz.

## **2.2.2 Virtual Reality Headsets**

This section will give an overview of the VR headsets from the most popular vendors. Oculus and HTC are the leading vendors for PC HMDs [35], but the Valve Index has also captured people's interest after the release in 2019. Playstation VR has the largest market share, but becoming a Playstation developer is a more complicated process, which makes the HMD an unsuitable choice for a master thesis project. Since this project focused on standalone devices, the information about the other VR headsets' specifications are presented in Table 2.3, and the details have been moved to Appendix B.

### **Oculus - Standalone devices**

*Oculus Go* was the first standalone HMD by Oculus, released in 2018. The device is considered more of a proof-of-concept by many since it proved that a standalone device could

HMD	DoF	Tracking	FOV	Refresh rate (Hz)	Resolution
Oculus Rift	6	External	94	90	1080x1200
Oculus Rift S	6	Internal	110	80	1280x1440
Oculus Go	3	Internal	100	60/72	1280x1440
Oculus Quest	6	Internal	100	72	1440x1600
HTC Vive	6	External	110	90	1080x1200
HTC Vive Pro	6	External	110	90	1440x1600
HTC Vive Cosmos	6	Optional	110	90	1440x1700
Valve Index	6	External	130	80/90/120/144	1440x1600

Table 2.3: Overview of VR headsets

deliver an immersive VR experience. After the release of Oculus’s second standalone device, the *Oculus Quest*, the 3DoF experience of the Oculus Go feels more restrictive. The Oculus Quest supports the same controllers as the Oculus Rift S and has been met with admiration by both VR enthusiasts and the masses. Multiple innovative features have been added to the device. In November 2019, Oculus released Oculus Link, which lets people also use the device as a tethered HMD, by connecting it to a computer with a high-tier USB 3 cable. One month later, support for hand tracking was also added, which gives new possibilities for development.

The standalone Oculus devices run on Android OS, where users have access to the Oculus store. This means developers need to build the project as an Android package and optimize the game accordingly for the weaker hardware. The hardware is similar to the one found in the 2017/2018 flagship smartphones. Maintaining the devices’ recommended performance is more challenging than for the tethered devices. The devices’ battery time is also one constraint, lasting only 1-2 hours, but they can be used while charging.

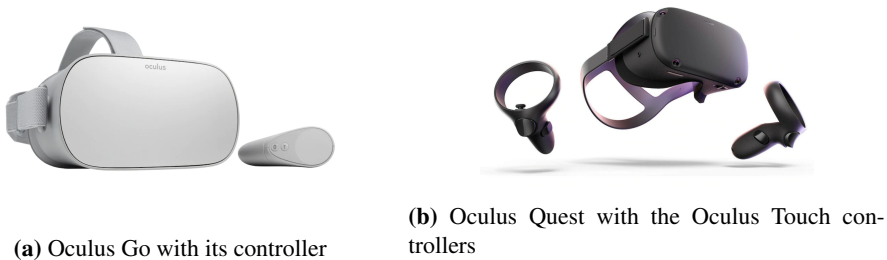


Figure 2.4: Oculus standalone devices

### 2.2.3 Game Engines

A game engine is needed to develop a VR application. For independent developers, there are mainly two game engines to choose from. One of them is called Unity, and the other one is called Unreal Engine. They serve much of the same functionality, essential for game

development. They come with built-in physics motors, handling of lights, audio, object interaction, the possibility of developing in 2D and 3D, scripting possibilities for adding custom features, and more of what people would expect from a game engine.

In addition to Unity's and Unreal Engine's similarities, they have some essential differences that need to be considered. One aspect to consider is the developers' prior knowledge of programming, working with 3D, animations, and experience with game development. Another aspect is the ambitions of the developer considering graphics and gameplay. A programming language is used, and the game engines use different two languages. This section describes how the game engines work and their differences.

## Unity

Unity is a game engine that supports development for a wide variety of devices, such as PC, Mac, gaming consoles, mobile devices, VR, AR, and more. The game engine can be used to create both 2D and 3D environments. Also, these 3D environments can be explored using VR headsets. Independent developers can develop games for free and publish their games as long as the money earned from the game is lower than a certain limit. A large number of resources are available for learning Unity. With Unity's massive community, these resources are available from first-party and 3rd-party companies, but also the community itself.

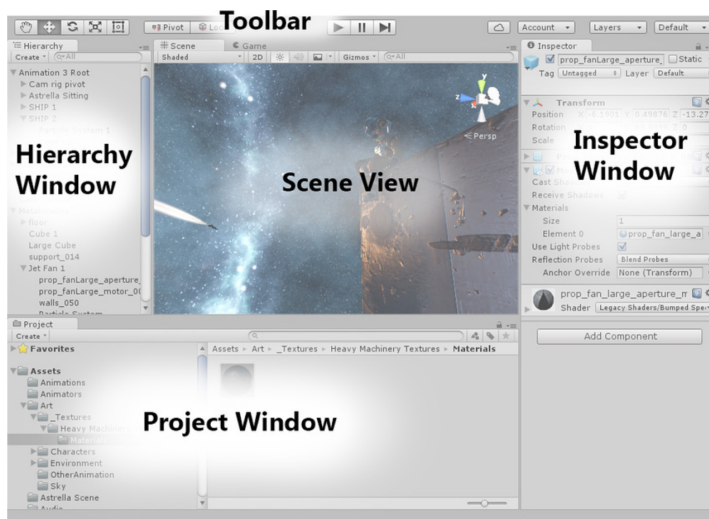


Figure 2.5: The Unity editor [3]

As a Unity developer, most of the work is done in the Unity editor window (see Figure 2.5) and in Visual Studio as the text editor for scripting. In the Unity editor, developers work in *Scenes*, where they place game objects with a variety of components that enable physics, audio, custom behavior, colliders, lights, and more. All the 2D or 3D game objects create the environment and is what developers see through the *Scene View*. Every object placed in the virtual world can also be viewed in the *Hierarchy Window*. To further examine specific

objects, the developer uses the *Inspector Window*, to adjust the object's behavior. To easily have accessible assets for the project, developers use the *Project Window*, to view and use all resources for the project.

One of the powers of Unity is through the use of *Prefabs*. A prefab is a game object with behavior that can be reused throughout the project. An example of a prefab can be a door with a custom animation that triggers on some event to open or close the door.

Unity enables efficient development through the powerful tools of keeping a good structure, built-in physics, colliders, and more. Developers can also test the game at the development stage instantly, by playing it through the Unity editor and edit the scene at runtime. Larger parts of a game can be built without any coding in the Unity editor, but coding is needed for the general game flow<sup>1</sup>, like for custom behavior of objects and handling input from the player. The language used for scripting in Unity is C#, a high-level programming language, that serves multiple paradigms. It is convenient for efficient game development, using its object-oriented programming disciplines.

As an independent developer, working alone or with few other developers, Unity is a good choice because of its intuitive user interface and built-in tools. The tools and features provided by Unity is known to be easily accessible, even for people without the deep game development competence. Nor is it necessary to use all of the tools and features to make a fully playable game. Still, the possibilities to add animations, self-made models, shaders, advanced audio features etc. should be simple to pick up and learn independently of each other to implement a game. C# as a programming language is known to be quite simple to pick up and learn. Without going into this in detail, C# compared to C++, which Unreal Engine uses, C# is known to enable more efficient development both because of how the language is built up and how easy it is to learn. C++ is known to be harder to learn, but it operates on a higher speed at runtime.

### Unreal Engine

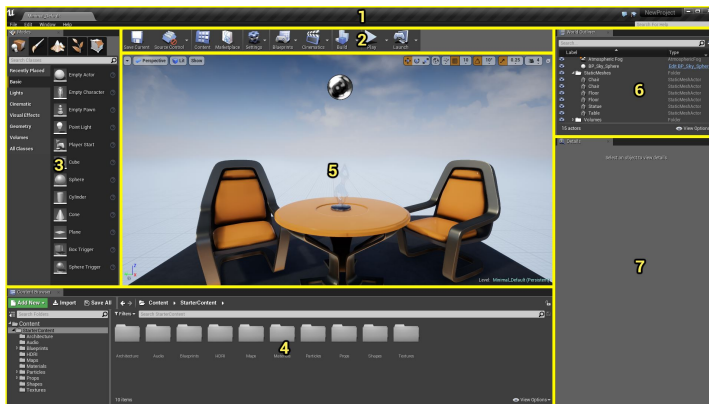
Unreal Engine is known for its astonishing graphics in games and is generally known for its powerful tools for developing graphics. Unreal Engine also supports both 2D and 3D development but is mainly known for 3D development. Unreal Engine is better suited for larger and more dedicated teams since the editor supports multiple views, where each developer can work independently with different parts of the process. One developer can work independently with animations, one with particles and another one with shaders. Unreal Engine also has a wide variety of learning resources available through its large community and interactive courses.

The main view of the Unreal Engine is the Level Editor. It shares many of the same elements as the Unity editor. Number 2 from Figure 2.6 shows us the *Toolbar* with quick access to the most used tools and functionality. Number 5 is the *Viewport*, where the current scene can be edited in 3D. A game in Unreal Engine is built up multiple scenes, where each scene is built up of Actors, which is any game object. All Actors are displayed in the World Outliner (number 6) and can be further inspected in the *Details* panel (number

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<sup>1</sup>Game flow, in this case, means the progress through the game.





**Figure 2.6:** The Level Editor of Unreal Engine [4]

7). In the bottom, the *Content Browser* (number 4), consisting of all reusable content for the project, is shown. Number 3 shows the *Modes* panel, which has powerful tools for creating geometric figures, placing new assets, editing meshes, and doing other 3D manipulations. All in all, the main panel shares many of the same features with the Unity editor. However, in Unreal Engine, there are also multiple other Editors where the different developer roles work. Since Unreal Engine was not chosen for this project, the details of these editors will not be given, but this is where Unreal Engine shows its true power for larger teams.

Instead of being exclusively dependent on scripting to implement the game flow and gameplay, Unreal Engine uses something called the *Blueprints Visual Scripting* system. Here developers can define gameplay and game-flow using a node-based system. Object-oriented classes or objects for the game engine can be defined here. This system can further be examined and worked within C++ to make more custom functionality than what comes out-of-the-box. The Blueprint Visual Scripting system is known to be helpful for developers, but an understanding of C++ is still needed to understand it entirely. With a higher learning curve of learning C++ properly, the advantage of this system needs to be weighed up against C#. As mentioned in the introduction for the game engine section, it boils down to ambition and team size, whether Unreal Engine is a better choice than Unity for the project or not.

## 2.2.4 Software Development Kits

Multiple Software Development Kits (SDK) are available for VR development. For accessing hardware, there are two main SDKs. The Oculus SDK was made for Oculus devices and the OpenVR SDK for HTC Vive, but both work for tethered Oculus and HTC devices. However, OpenVR does not support the standalone Oculus devices. On top of the hardware SDKs, other SDKs have been built to provide APIs, prefabs, scripts, or other useful resources for more efficient development. Since the choices of SDKs are dependent on which game engine is used, the choice of game engine was made before the exploration

of SDKs. Section 3.3.1 describes why Unity was chosen for this project.

This section describes the most popular SDKs used for VR development in Unity and their differences. It is important to note that the SDKs are changing rapidly, and new versions and SDKs are introduced from time to time. Through the time of this thesis, much has changed. It is crucial to get an overview of the latest technology in order to make the best choice for a project.

### **Oculus Integration**

The Oculus Integration [36] is an SDK provided by Oculus as a Unity package. It provides scripts, prefabs, and other useful resources for VR development for all Oculus devices, but also support OpenVR devices with a few restrictions. The SDK includes APIs that enable VR camera behavior and handling of controller input. The package also provides scripts for grabbing objects, haptics for controllers, prefabs for hands or controllers, and other useful resources for VR development. In addition to this, the package comes with a sample framework that includes scenes demonstrating best practices for how the different resources in the package can be used. In Unity, the standalone devices, such as the Oculus Go and Oculus Quest, are restricted to using this SDK.

### **SteamVR Unity Plugin**

The SteamVR SDK [37] is delivered by Valve and is meant to simplify VR development in Unity, by providing one API for the most popular VR headsets. This SDK provides resources for handling camera behavior, and controllers like Oculus Integration does. It also provides an interaction system that helps the developer handle interactions between the virtual world created in Unity and the APIs provided by SteamVR. This SDK also comes with a sample framework. SteamVR is the most popular SDK used for VR development since it supports such a wide variety of VR headsets. Therefore, it is also well-documented, and plenty of learning resources are easily accessible. One restriction with this SDK is that it needs to run on a Windows or Mac computer, and therefore it only supports tethered VR headsets.

### **VRTK**

VRTK is an abbreviation of the Virtual Reality Toolkit [38]. It can be used together with both Oculus Integration and SteamVR Unity Plugin, with a little "glue code". VRTK can be set up to communicate with the camera and controller behavior from the SDKs mentioned above. The developers of VRTK has a goal of making VR development more productive, by providing useful prefabs. The toolkit provides prefabs that simplify interaction with objects, implementation of locomotion such as teleport, snap zones for objects or teleport curves, and interactions with "physical" objects such as drawers, buttons, etc. The developers of VRTK has made an example project where all the resources are implemented in different ways. The variety of resources VRTK provides can be implemented without the toolkit, but doing so would demand more time from the developer.

### **XR Interaction Toolkit**

Since the beginning of this project, much has changed and been improved for VR SDKs. In the end of December 2019, Unity released the XR Interaction Toolkit [39]. All that Oculus Integration provides was added to the Oculus XR Plugin, and it can be imported using the package manager. The toolkit provides support for all VR and AR devices supported by Unity. Also, it provides everything necessary to implement interaction and locomotion. The toolkit was still in preview at the end of the master thesis, which meant that much of the functionality was still experimental.

Since the choice of SDK was made before the release of the XR Interaction Toolkit (see section 3.3.3), the toolkit was not considered for the project. This shows that a lot is happening within VR, and that to choose the right SDK, a large amount of exploration is needed to make the right choice.

## **2.3 Related Work**

Through the literature study, no similar projects where VR has been applied in AI education were found. VR applications exist for a variety of STEM courses. This section will present examples of these applications to understand how VR is best applied in these courses. The insight is useful to understand how VR can best be utilized for making AI education engaging. Then, the section presents some interactive projects used for teaching AI. In the end, the concept of educational escape rooms and virtual memory palaces are presented, since the concepts were thought to have the potential for teaching AI in an engaging way.

### **2.3.1 VR in STEM courses**

A variety of VR applications exist for teaching STEM courses. This section will present applications and discuss how the concepts can be mapped for teaching AI in VR. What the applications have in common is that they utilize the technology with interactions and visualizations that are otherwise difficult or impossible to experience.

#### **Virtual Labs**

One of the more comprehensive works for teaching STEM studies is the *LabsterVR* [40] application. It teaches topics from multiple subjects, like cell and molecular biology, ecology, and physiology. The user can conduct experiments and explore molecules or other concepts that would otherwise be expensive, dangerous, or difficult to experience.

*ClassVR* [41] lets students learn a variety of subjects by being immersed in concepts that are otherwise hard to experience. Students use lecture plans that teach one specific topic. The lecture plans combine the use of traditional teaching methods with 3D models or scenes that the students can explore. Students are immersed in topics like physics, chemistry, mathematics, mars travel, and more.

## Algorithms and Data Structures

Some of the previous master students at NTNU's XR Lab focused on using VR for teaching algorithms and data structures. From the literature study, these projects were probably the ones with the highest relevance to this project. In one of the projects, a VR application was implemented for teaching sorting- and graph algorithms [16]. There were no final conclusion on whether VR improves the learning process. However, with the available results, there were positive indications that the users were interested in "learning-by-doing" tasks where they can interact with their hands and get a score based on performance. The application was considered to have the potential to be used as a supplementary learning tool.

The project did not only focus on algorithms and data structures specifically but also looked at what makes VR good for learning in general. One key point is that the users were positive to the interactions made in VR, which would otherwise be hard to recreate. This points to the importance of not simply mapping concepts that work well in other educational tools, but instead tailoring something different for VR. Since very few projects have focused on using VR in computer science courses, it is useful to see the opinions users had on using VR in this context, to understand how VR can be applied in a meaningful way for AI. The results showed that users were neutral to positive to this, which makes it interesting to look more into how VR can be applied in computer science courses, such as AI.

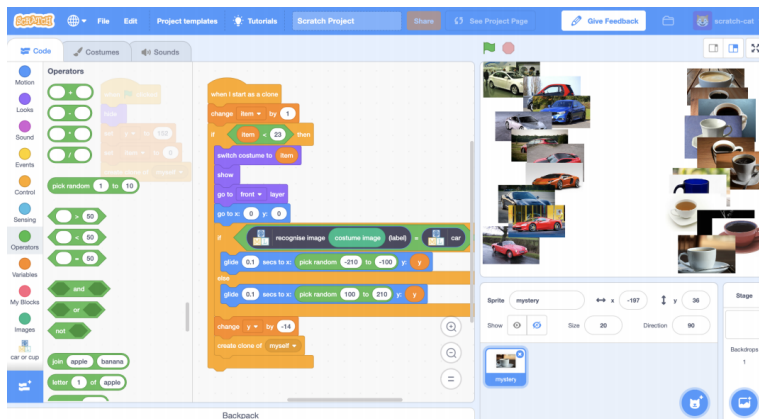
### 2.3.2 Interactive Projects for Learning AI

With the increasing popularity and need for applying AI in a large amount of sectors, a variety of interactive games and interactive projects have become available as an attempt to increase the knowledge of AI. This section will first focus on games and interactive projects for the general population, and then discuss what is available for students and developers.

#### Increasing the population's competence

In 2018, the Finnish company Reaktor and the University of Helsinki launched the course "*Elements of AI*" [11]. The course is meant to give a basic introduction in concepts within AI so that people can understand what AI can and can not do. They have a goal of educating 1% of European citizens on the basics of the topic. Since AI affects more and more of our daily lives, the course is highly relevant for everyone. The course combine theory and practical tasks. One of the course chapters gives an overview of neural networks to give insight into how deep learning works. This is the same topic as the VR application for this project will cover, but the VR application will go much more in-depth to teach AI students.

Some of the interactive projects available teach kids and youth about AI in a simple and engaging way. They are taught the logic of coding through interfaces where pseudo-code is built by "drag-and-drop". Machine Learning for Kids [42] is a collection of projects that teaches students to create everything from chatbots, different types of image recognition,



**Figure 2.7:** Machine Learning for Kids - cup or car [5]

escaping from monsters, making tourist recommendations, and more. The projects reflect the real world of machine learning well, since the process of building the ML models, consists of the process of predicting user input, building a data set of examples, training the model based on the data, and then scripting responses. Figure 2.7 shows a project, where the goal is to recognize cars or cups. The insight students gain from these kinds of games and interactive projects are relevant for making more people interested in studying computer science and increasing the population’s awareness of how digital media affect our everyday lives.

### Interactive projects for students and developers

A variety of interactive projects are available for students and developers as well. Google has developed the Machine Learning Crash Course [7], which combines the use of text, illustrations, videos, and hands-on projects. A few other interactive projects exist for learning about AI topics, but none that use game elements were found. Google Experiments is an entertaining “showcase” of how AI is used to solve real-life problems. Visualizing the use-cases of AI, like in Google Experiments, may motivate students to learn more about AI. There might be potential in visualizing these concepts in VR to immerse the user in AI use-cases.

### 2.3.3 Educational Escape Rooms

Escape rooms are games where players need to find clues to solve puzzles that allow them to progress through one or more rooms. These kinds of games are often used for team-building activities, where the team needs to solve the puzzles within a limited time frame to succeed. A variety of studies have shown the success of educational escape rooms in STEM courses [43, 44, 45, 46, 47]. The escape room activity originated from Japan in 2007. However, the educational use is an emerging field [48], which makes the concept interesting to explore. Escape room VR games have reached high popularity, both for

single-player and multiplayer experiences.

In 2019, a study examining the use of an educational escape room for teaching programming in higher education was published [49]. For the project, an educational escape room was created to teach web development. Through an intensive amount of work, they created a class-room escape room activity, consisting of both physical and computer-based puzzles. The students worked in pairs solving the puzzles sequentially in a limited amount of time while being immersed in a narrative. The paper refers to the success of using educational escape rooms in STEM studies. It claims to be the first to explore the instructional effectiveness of using an educational escape room in a programming course. The project results show that the use of an educational escape room in this setting has very positive impacts on both engagement and learning. Also, the students preferred this method of learning, compared to traditional learning methods.

One important insight from López's project [49], which is highly relevant for VR, is the positive impacts the physical puzzles had on the experience. The mechanics of the physical puzzles allowed the students to assemble and manipulate physical objects in ways that were not possible through digital challenges. However, this may be possible through immersing the user in a virtual world. For future work, the study mentions that one valuable direction would be to explore the same concepts in VR and AR. One study was found, where they applied VR as part of the educational escape room [47], but no studies where the whole educational escape room experience happened within VR was found.

### 2.3.4 Spatial Memory Palaces

Since the ancient Greek/ Roman times, a memory game called the "Method of loci" has been used to have imaginary journeys through some familiar environment for remembering information. One of the advantages of VR is that this virtual mind palace can be recreated and give the user the feeling of actually being present to improve learning. The journey can be recreated for a regular monitor, but the feeling of presence is much stronger in VR.

A variety of studies have been conducted to see how the spatial presence in VR affects the learning outcome. In 2018, a study looked at how the spatial presence in VR affected memory retention and motivation for language learning [50]. Their results suggested that the spatial presence helped students in remembering words more efficiently. Another more comprehensive study compared 40 people's ability to recall information learned through an HMD and on a regular monitor using a mouse [15]. The users were requested to remember faces, placed around in different environments. The study showed that people had an 8.8% better recall accuracy using the HMD, which apparently was a significant difference. One study also showed that students scored significantly better after learning abstract chemistry topics in VR compared to using a monitor-based system [51].

If the advantages of using VR for learning is as good as these studies suggest, there is a high potential creating a virtual memory palace in VR, and incorporate escape room and gamification elements to make the experience exciting. Read more about how these ideas were put together in section 4.1.

# Chapter 3

## Methodology

This chapter describes the research and development methodologies used, how and why the project was divided into two phases, technology choices, methods for user testing and evaluation, and data generation methods.

### 3.1 Research Methodology

At an early stage of this project, it was decided that a new VR application should be developed and thoroughly evaluated. An overall research strategy was chosen to support the process.

#### 3.1.1 Research Strategy

As a research methodology, the Design and Creation method from "Researching Information Systems and Computing" [52, chap. 8] was used. The strategy focuses on developing an IT artefact<sup>1</sup>. In this case, the plan was to develop an application, which by the book is called an "instantiation". An instantiation is defined as: "A working system that demonstrates that constructs, models, methods, ideas, genres or theories can be implemented as a computer-based system". The methodology involves working in an iterative process of five main steps.

There was none existing literature about using VR in AI education. Therefore, the Design and Creation strategy was considered suitable since parts of the research outcome would be an IT artefact.

1. **Awareness:** This step involves researching the problem itself and reading relevant literature. It was done through a literature review, which was presented in chapter 2.

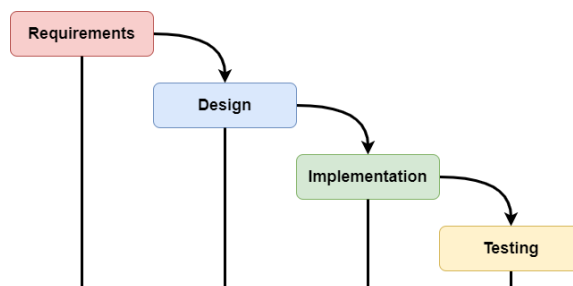
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<sup>1</sup>An IT artefact is either a construct, model, method, or an instantiation.

2. **Suggestion:** In this step, a very tentative idea of how the problem may be addressed is proposed. The concept for the Phase 2 application is presented in section 4.1.
3. **Development:** This is the step where the concept is implemented. Since the results from the previous step are very tentative, the project is dependent on using a system development methodology to assure quality. The chosen development methodology is presented in the next section, and the details of the development step are presented in chapter 4.
4. **Evaluation:** In this step, the application resulting from the previous step is evaluated. The goal is to figure out if the application lives up to expectations. In this project, the applications from both phases were user-tested and then evaluated using the data generation methods presented in section 3.4.3.
5. **Conclusion:** In this step, a more meaningful overview of the results gained from the process is documented, and the new knowledge gained and whatever remains unsolved is identified. In this step, a response to the project motivation and research questions is made. The conclusion of this project will be based on the results of both phases of research.

### 3.1.2 Development Methodology

By using a development methodology, the quality of both the application itself and the research project is assured by guiding the project through the stages of analysis, design, implementation, and testing. It was decided to use concepts from the Waterfall Model as a development methodology in Phase 2, but since this was a solo project, the need to strictly follow a method was not as high as in regular IT projects.



**Figure 3.1:** The steps from the Waterfall Model used in this project.

The process used for developing the VR application is shown in Figure 3.1. First, some requirements were defined based on the concept. The next step was to define a design and then implement the application. Since many discoveries were made through conducting minor tests conducted along the way, the design and implementation steps were executed iteratively until a satisfactory solution was achieved. Some times there was a need to go back to the requirement step as well.



Github was used for version control, with a simple workflow suitable for solo projects. The tool ensured that the project could be rolled back to a stable version in case something went wrong. The project is available in a public repository on Github [17].

## 3.2 Phases of the project

This section describes why and how the research project was divided into two phases.

### 3.2.1 Phase 1

At the time of discussing the topic of the master thesis, someone were already working on a project about using VR in deep learning education. Håvard Snarby, a former master student at the supervisor's XR lab, was developing a VR application, intended for the course "*TDT4195 - Visual Computing Fundamentals*" as an educational tool. It was decided that the author was going to participate in the evaluation of the application. The reason for this was that the author could keep on working on the project with new concepts and improvements. The author's contribution to the existing project was to plan and execute user tests to use the evaluation as a foundation for Phase 2.

Another reason for participating in the existing project was that previous VR projects at the lab ended up not being properly evaluated, due to a low amount of remaining time after learning and development. By participating in the existing project, the author got a higher competence in VR development at an earlier stage, which was beneficial for efficiently developing something of his own. Also, with a minimal amount of similar work in the field, it was beneficial to build on the ideas from the Phase 1 application, since the learning curve was quite steep. Read more of about this in section 6.4.

### 3.2.2 Moving from Phase 1 to Phase 2

After evaluation, we revealed that the project had great potential. We realized that the application proved to work well as a proof-of-concept, but that the application needed to utilize the VR technology more by adding more immersive elements, both for learning materials and the tasks. It is recommended to read the results and discussion from the evaluation of Phase 1 to understand the thoughts and ideas made for Phase 2 entirely (see section 5.1). We decided that the project could benefit from being looked at with a pair of fresh eyes. To avoid spending large amounts of time understanding the code base of the existing project and to have the freedom of implementing completely new concepts, it was decided to start from scratch with a new Unity project.

### 3.2.3 Phase 2

Phase 2 followed all the steps of the Design and Creation research strategy. A new concept was defined based on the evaluation of Phase 1, and since there was a need to find completely new ideas, it was also based on the literature study. Phase 2 should not be regarded as a new iteration of development, but rather as a fresh start.

### 3.3 Technology

This section will discuss the choices of technology made for the Phase 2 application. The options considered were presented in section 2.2. Figure 3.2 gives an overview of chosen the architecture. The implementation of the application will be documented through chapter 4.

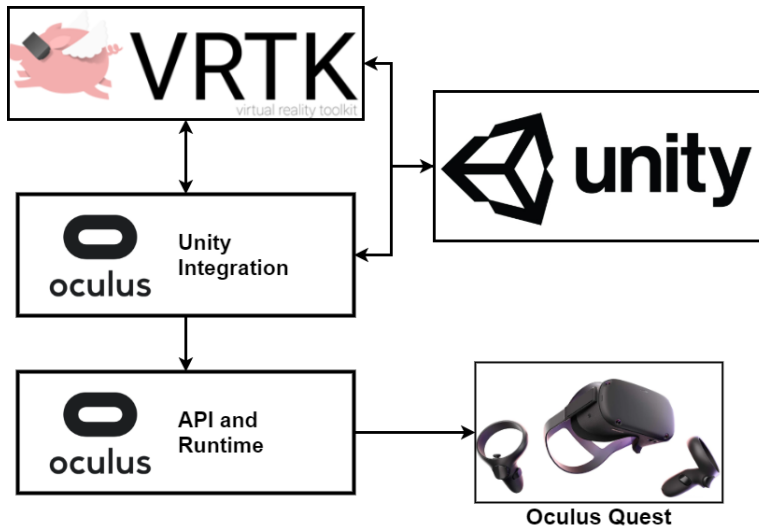


Figure 3.2: A simple representation of the chosen architecture.

#### 3.3.1 Game Engine

Unity was considered the most suitable game engine since Unity is simpler for an independent developer. Unity has a lower learning curve than the Unreal Engine, which is suitable for a new game developer. It was decided only to use free assets and not spend too much time on the application's graphical work. This would give room to focus more on implementing concepts, tasks, visualizations, and more. The goal was to develop a prototype to test the concept and not a final VR application. Therefore, the powerful tools of Unreal Engine were not needed, and Unity proved to be a good candidate for fulfilling this goal. Also, the author had much experience with the programming language Java, which shares many similarities with C#. It was decided to use the latest LTS (Long Term Support) version of Unity to stay on a more stable version that provides extended support.

#### 3.3.2 Virtual Reality Headset

Oculus Quest was chosen for the project for two reasons. The first reason was to be able to conduct multiple simultaneous user-tests efficiently. The second reason was to develop an application that is more easily accessible to students. The HMD is fully standalone and uses inside-out-tracking, which enables 6DoF for both headset and controllers. Compared

to a tethered device, that requires an HMD, computer, monitor, cables, sensors, and more, the Oculus Quest only requires the HMD and controllers. The time required for setting up a test environment for multiple users anywhere is quite low. Also, the feeling of being entirely disconnected from a computer can make the experience more immersive. The Oculus Rift was used through the implementation phase to run the application directly from the Unity editor. The application was also built to be tested on the Oculus Quest, but since this takes time, it was only done when new functionality was complete.

One disadvantage of developing for the Oculus Quest is that it may demand a more considerable amount of optimization efforts to fulfill performance requirements. The resulting application of this project was thought to be kept simple enough to run well on the weaker hardware. Using the Oculus Quest also put some restrictions on the use of SDKs. This is further discussed in the next section.

### **3.3.3 Software Development Kits**

The Oculus Integration Kit was used for hardware integration, and VRTK v4 was used for interactions. By using a little "glue-code", the Oculus Integration Kit can be set up to work with the VRTK prefabs. The choices for SDKs made it possible to port the application to Oculus Rift and Rift S with ease. Also, by using VRTK, it should be possible to port the application to support OpenVR devices as well. The SteamVR is more well-documented than the ones chosen for the project, which probably made development a little more complicated. However, with the release of the Oculus Unity Learn course for VR development[53], it was easier to get an overview of the fundamentals and develop with less documented SDKs. Also, by using online forums and the VRTK Slack group, complex problems could be solved, where no documentation was found.

The SDKs are improving and changing rapidly, so getting an overview of the latest technology before making a choice is crucial. The choice of SDK was made at the end of November 2019, but only one month later, Unity released the XR Interaction Toolkit. Also, through the time of the project, multiple new versions of Oculus Integration and VRTK was added. The choices made for SDKs seemed to be the best option in November 2019, but if the decision was made only a few months later, something else could have been better.

## **3.4 Evaluation**

This section will first describe the initial plans for user testing. The testing method was planned for both phases, but was not feasible for Phase 2, due to the situation with Covid-19. Therefore, the new methods used for online evaluation will be presented in the next section, and then the methods used for data generation will be described.

### **3.4.1 Phase 1 Evaluation**

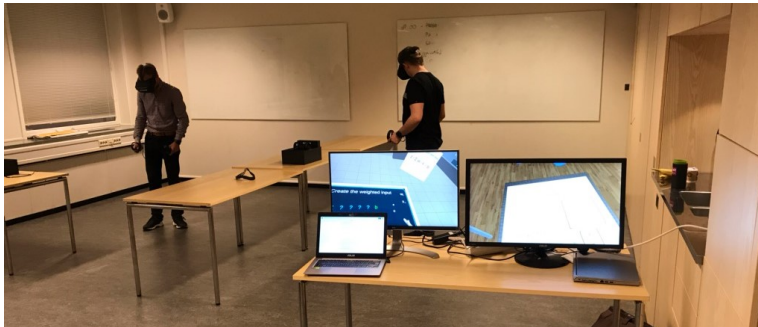
In Phase 1, an application developed by Håvard Snarby for the overall project was evaluated. The application is presented through videos in section 5.1.

## User Testing

User tests were conducted to explore the usability and to get feedback on opinions related to the concepts introduced through the application. People from the target audience were requested to meet up at the test environment to play through the application. Each user was observed, asked to fill out a questionnaire, and most of them were interviewed.

To efficiently conduct user tests without too many prerequisites for the test environment setup, 6 Oculus Quest HMDs were used, so that multiple users could user test simultaneously. Read more about the choice of HMD in section 3.3.2.

### Setting up the test environment



**Figure 3.3:** Håvard Snarby and Sølve Bø Hunvik in the user test environment.

Prerequisites for the user tests:

- Before the user tests, students signed up for a time slot. Each user was given a maximum of 1 hour to play through the application. The supervisor managed registration.
- A large room was rented, with enough space to execute multiple user tests at the same time.
- Each user was given a 2.5 by 2.5 meters play area, where the Oculus Quest Guardian System was already set up.
- Each Oculus Quest was connected to the same account and was marked with its connectivity ID. This allowed test personnel to connect to the HMD and see a live video feed through the phone or using a Chromecast.
- Some Chromecasts were set up on a computer screen for virtual observation.
- Cleaning equipment was accessible to clean the HMDs between each user test properly.

### 3.4.2 Phase 2 Evaluation

The application evaluated in Phase 2 was developed by the author. The implementation details can be found in chapter 4, and the results in section 5.2.

When Covid-19 arrived in Norway and started spreading, the government brought the country into lockdown and laid out guidelines restricting social interaction. The decision meant that also campus had to close, and all social interactions had to happen online. Therefore, it was not possible to conduct user tests as intended. The initial plan was to invite as many students as possible from a course called *"Computer Vision and Deep Learning"*. Inviting this many people in the times of a global pandemic would violate the government's guidelines since too many people would have to gather in the same room. Also, no amount of cleaning could justify the risk of spreading the virus by using the same HMD.

The global pandemic was a little drawback to the project. However, instead of ending up not evaluating the application, it was decided to put large amounts of effort into reaching out to users online. Therefore, two alternative ways of evaluating the application was planned and conducted:

- **Online user testing:** The application was distributed online. People could submit feedback after playing through the whole application or from the game menu.
- **Video evaluation:** A video describing the core concepts of the application was created and distributed online, along with and a questionnaire.

The subsections below describe the new audience and elaborate on thoughts, plans, and execution of online evaluation.

#### Expanding the Audience

The intended audience was people in introductory deep learning courses. After some consideration, it was concluded that it was not necessary to restrict the audience to such a small group. The audience was instead extended to anyone within the field of computer science, with interest in AI. The new audience was much larger, but it was assumed that after studying computer science for 4-6 semesters, the students should have enough overview of the field to understand the topic and give useful feedback.

#### Reaching out in Online

In online forums, technology enthusiasts can discuss anything related to VR and AI. People in these forums often have a higher interest in technology, which leads to a high level of engagement. On Reddit, there are multiple subreddits<sup>2</sup> for people interested in VR and AI. Examples of subreddits are *r/OculusQuest* [54], *r/oculus* [55] and *r/artificial*. It was decided to reach out on Reddit to see if people were interested in testing the application or watching the video before submitting feedback. Also, it was made attempts to reach out

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<sup>2</sup>A subreddit is a sub-forum, that creates a community for a specific topic. They are referred to as *"r"/subreddit name"*.

to the IMTEL network [56] to AI research groups, AI students, and others within the field of AI.

This way of reaching out was considered a good alternative to the initial plans since there were not many options for reaching out. With the global pandemic, people were spending time locked up in their homes looking for things to do, and therefore also hopefully being willing to help others. It was also highly likely that people in the VR subreddits possessed a VR headset. The idea was a bit ambitious since there was no guarantee that anyone wanted to test the application at all.

Posting the project in subreddits with more than 100.000 people from the entire world came with a few risks/problems that needed to be addressed. A post in the subreddits could attract people with bad intentions, which could possibly lead to unreliable feedback. Also, it was likely that not everyone were computer science students. Fewer data generations were available and a post could quickly disappear in the flow of other posts.

### Online Evaluation Approach

Posting the application in an online forum, requesting voluntary evaluation required a carefully prepared approach. Two main elements were considered essential to motivate people to participate. The former was in the user's best interest, hoping for the user to gain something by learning about AI/Deep Learning. The latter was hoping that the user would sympathize with the problems caused by the global pandemic, and therefore want to help. The posts were written compactly, showing gratitude to anyone participating.

It was decided to keep the amount of effort giving feedback to the minimum to avoid losing potential participants. Therefore, for data generation, a simple questionnaire was used to measure people's opinions on a 1-5 scale quantitatively. Also, an optional written question was added to get feedback for qualitative analysis.

- **Online user testing:** The application was uploaded to a Google Drive folder, with guides for installation. The questionnaire was integrated into the application to ensure that participants tested the application before leaving feedback. See the final feedback solution in section 5.2, and the questionnaire used in Appendix section C.2.1.
- **Video evaluation:** The voice-over video in Table 5.2 was shared with a link to a Microsoft Form questionnaire where the video was integrated. The video evaluation started almost two months after the online user testing, which gave time to deeply consider and improve the questionnaire (see Appendix section C.2.2). Since the users were only going to watch the video and submit the questionnaire, they would not have the same insight as someone who actually played through the application. Users were encouraged to respond to the questionnaire as well as they could, based on assumptions. They were also given a chance to watch a full play-through or play the application.

### 3.4.3 Methods for Data Generation

The set of methods presented below were used to generate data for evaluation. Questionnaires were mainly used for quantitative analysis, but also qualitatively through written feedback. Interviews and observations were used for qualitative data analysis. Only questionnaires were used in both phases of the project.

#### Questionnaire

The questionnaire was the main method used for data generation through the project. One of the advantages of a questionnaire is that the researcher can obtain and analyze responses from a large number of people in a standardized way [52, chap.15] since each question or statement has a pre-defined set of answers. The questionnaires were used to quantitatively evaluate the application by measuring people's opinions related to various statements on a 1-5 scale. Neutral responses were interpreted in one of two ways, depending on the statement. Either the participant does not have a strong opinion, or it is a three on a scale from 1-5.

In Phase 1, a System Usability Scale (SUS) [57] schema was used. SUS is an efficient and reliable tool for measuring usability, even with a lower amount of responses. The other statements were meant to measure learning and engagement. In the online user test in Phase 2, some statements were reused. However, since the users were assumed to have much more experience with VR and therefore probably would not reflect the real target audience, it was decided not to conduct a full SUS. The decision gave room to focus more on statements about learning, engagement, and the concept. See the questionnaires used in Phase 2 in Appendix section C.2.1 and C.2.2.

The questionnaires were created using Microsoft Forms, a tool for creating and sharing a questionnaire, and easily analyze the data. Before user testing, the questionnaire was discussed with the supervisor, to refine and improve the contents. All responses to the questionnaire were anonymous.

#### Observation

Observation is a useful data generation method to collect valuable data on how a user behaves and interacts with an IT artefact [52, chap. 14].

Users were observed in two ways in Phase 1:

- **Physically:** There is a risk of experiencing discomfort in VR since the user is fully immersed in a virtual world. The test personnel tried to discover any physical signs of discomfort.
- **Virtually:** A live video feed of what the user saw was sent to a Chromecast, to see how the user interacted with the application. This was done to get an impression of the application's usability and how users solved tasks.

### **Interview**

Users were interviewed after testing the application in Phase 1. The reason for conducting interviews was to get a deeper insight into the user's interests, feelings, opinions, dissatisfaction, ideas, etc. to be able to improve the concept and application. The goal of gaining this insight was to build a foundation for Phase 2, where new concepts could be introduced, improved, or scrapped.

The type of interviews carried out in this project were semi-structured. By definition from Oates [52, chap.13], this is a type of interview, where the researcher has a list of themes to cover, and questions to ask. The interviews conducted in Phase 1 followed the conversation's flow rather than the order of questions. Processing the data gained is much more time consuming than other data generation methods, but the thoroughness often leads to interesting results. These questions were used:

- 1. What do you think about this way of learning?*
- 2. Were there any tasks that you think worked better than others?*
- 3. Were there any tasks that did not work as well in VR?*
- 4. Do you have any suggestions for how the application could be improved? Ex. consider tasks, presentation of information, or gamification.*
- 5. We are looking for ways of making the application more engaging. What do you think about using elements from for example escape rooms on top of what already exists?*
- 6. What did you think about the tutorial? Were there any parts of it you found difficult?*



# Chapter 4

## Implementation

This chapter describes the efforts put into creating a new concept, defining requirements, designing, and implementing the new application developed in Phase 2. A new concept was defined, based on results from Phase 1 and the literature study.

Without much previous competence in game development, VR, and deep learning, the author spent an extensive amount of time learning the technologies and necessary theory. The learning was done simultaneously with Phase 1 and the other work related to the project.

At the time the author started participating in Håvard Snarby's project, the Phase 1 application had a quite incomplete tutorial. After conducting a few minor user tests, we realized that the lack of training led to confusion through the application. The discoveries started the process of formulating requirements and designing the tutorial. The author set up the fundamentals in a new Unity project and implemented the tutorial. The work was done through December 2019, before the Phase 1 evaluation, as a part of learning and to lay a foundation for later development.

After the discoveries made in Phase 1, we realized that there was a need to have a fresh start, rethinking tasks, and learning materials. Phase 2 started, and the development process lasted from January to the middle of April 2020.

## 4.1 Concept

This section gives an overview of the process of defining a new concept for Phase 2.

### Defining a new concept

Seeing that users were generally very positive to the concept in Phase 1 (see section 6.1), it was decided to build on some of the ideas that worked well and introduce new concepts where things did not work as well. Users saw the potential of using VR, but there was a need to utilize the technology more. A new concept was defined based on the feedback from Phase 1 and related work presented in chapter 2.

Users were very positive to use more escape room elements, to make the application more engaging and challenging. Section 2.3.3 discussed positive results of using educational escape rooms in STEM studies. In the study by López, where they applied it in a programming course [49], they proposed looking into integrating these concepts in VR as future research. One important insight from López's study was how immersive and engaging the physical puzzles were. Users mentioned in Phase 1 that the tasks were repetitive and did not justify the use of VR, but they were more positive where 3D objects were used. It was decided to find ways to recreate the concepts by creating 3D puzzles for building neural networks, formulas, and more. López also recommended presenting tasks in a sequential path, since this requires less guidance and simpler progress for students. It was by the author's impression that following the curriculum more sequentially would lead to less confusion and a higher learning outcome. To utilize the advantages of virtual memory palaces (read section 2.3.4), it was decided to split topics into separate rooms.

### Deep Learning Introduction in VR concept

The new idea was to provide a single-player educational escape room experience in VR to students interested in getting an introduction to deep learning. The application should cover the concepts; neurons, cost functions, gradient descent, and backpropagation. Students are immersed in exciting rooms, where they are taught the curriculum sequentially, though solving puzzles, calculation, and quizzes, based on the course-material. Every topic is placed in a separate room to enable spatial memory and allow the user to focus on one thing at a time, without being distracted by materials that build on new theory. The application utilize VR by giving 3D visualizations of the curriculum's elements; neural networks, gradient descent, formulas, and more. There should be a mix of "physical" puzzles, where the user needs to manipulate 3D objects and quizzes. The learning materials introduced through the application should utilize text, audio, animations, and 3D-visualizations to immerse the user in the curriculum's contents. In the end, the user should be able to put together everything learned, through a more open-ended puzzle.

The intended target audience is computer science students interested in AI and deep learning, but should also be accessible to anyone interested in the topic. Many people in the audience will be new to VR, which makes it essential to have a thorough and intuitive tutorial.

## 4.2 Requirements

This section shows the non-functional and functional requirements defined for the application.

### Non-Functional Requirements

The main goals of the application were to discover better ways of presenting learning materials, improve or define new tasks, and introduce escape room elements. Developing something new for VR can be time-consuming. For example, if the plan is to implement a new type of task, the developers/designers need to go through these steps; a design is sketched, the right assets are created or found, every object is set up in the 3D environment, scripts are written and should communicate correctly, and every interaction needs to be intuitive for the end-user. The process does contain even more steps, but the point here is that it is a lengthy process. Some essential non-functional requirements were defined, that was in focus through every step of the development process.

ID	Type	Requirement
NFR-1	Reusability	Every design, object, interaction, and script should be easy to reuse to create more content.
NFR-2	Usability	There should be a high focus on usability for every interaction and interface in the application. The application should be designed following a user-centered design process.
NFR-3	Modifiability	A component-based design pattern should be used to reduce dependencies so that changes can be made without hassle.
NFR-4	Extensibility	Possibilities for adding new content or features should be facilitated.
NFR-5	Performance	Since the application is intended for the Oculus Quest, which has weaker hardware specifications than tethered HMDs, there should be a focus on keeping a good performance throughout the application.

**Table 4.1:** Non-functional requirements

**Tutorial - Functional Requirements**

<b>ID</b>	<b>Requirement</b>
T-FR1	The user should be taught how to grab an object.
T-FR2	The user should be taught how to move and place objects.
T-FR3	The user should be taught how to navigate the room, using teleportation.
T-FR4	The user should be taught how to hold objects while teleporting.
T-FR5	The user should be taught how to interact with "physical" User Interfaces <sup>1</sup> .
T-FR6	The user should be taught how to interact with regular user interfaces (menu) using the pointer.
T-FR7	For every new type of interaction type, a textual description should be given along with a visual representation of the controller, to help users of any skill level.

**Table 4.2:** Tutorial functional requirements**Deep Learning Introduction - Functional Requirements**

<b>ID</b>	<b>Requirement</b>
FR1	Each room of the application should focus on one topic only. Each topic may be split into smaller series of rooms.
FR2	The learning materials should utilize text, 3D visualizations, audio, video, and animations.
FR3	The learning materials should be placed in an intuitive sequential order.
FR4	After each topic, the user is tested in the topic through multiple-choice questions (quiz).
FR5	The first task should be an easy task of teaching how the perceptron neuron output is calculated.
FR6	The user should be taught how the sigmoid neuron works, through finding the weighted sum and using a calculator to calculate the activation.
FR7	A 3D visualization of the cost function surface should teach the user gradient descent.
FR8	The user should be taught neural network notation through correctly placing activation, weighted sum, bias, and weights in the right position in a 3D neural network.
FR9	An animation teaches how backpropagation works.
FR10	The user is taught how the chain rule is used to find partial derivatives by placing 3D objects in formulas.
FR11	The user should be able to give feedback from within the application.

FR12	Each quiz should give a reward that the user can use to unlock the last room where he is congratulated for completing the application.
FR13	A more open-ended and complex task should put together everything the user has learned.

**Table 4.3:** Deep Learning Introduction functional requirements

## 4.3 Design and Implementation

This section goes in-depth about the design and implementation of the different parts of the application. The first two subsections explain how the fundamentals were set up, and the development of the tutorial. Readers who are not interested in how the fundamentals were set up and how the tutorial was developed are recommended to start reading from section 4.3.3.

### 4.3.1 Setting up the Fundamentals

The first part of the development was to set up Unity with the required SDKs. This section gives an overview of how the VR player was set up to communicate with the HMD hardware, locomotion, and visualizing realistic hands. Furthermore, a description of how room layouts were built efficiently and how interactable objects were set up is given. Lastly, the section describes how the game menu was built with extensibility in mind.

As mentioned in section 3.3.2, the new Unity Learn course by Oculus played an essential part in getting started with development. The course set standards for interactions and implementation, which probably saved large amounts of time for a new VR developer.

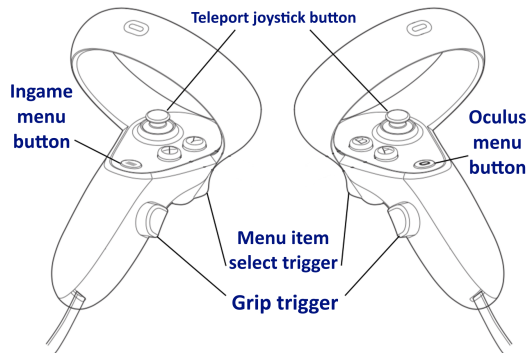
#### Technology Setup

A new Unity project was set up in the 2018 LTS version. The Oculus Integration Kit was imported from the asset store, and the VRTK Prefabs were imported to the project and made accessible through the package manager. Some of the project settings had to be adjusted to enable VR, and the physics update loop was set to update with a frequency of 72Hz, to play well on the Oculus Quest.

For setting up the VR player, the *OVRCameraRig* prefab was imported from the Oculus Integration Kit, to be able to communicate with the Oculus hardware. Then, the *TrackedAlias* prefab was imported from VRTK, and the object's references were set up so that everything from the *OVRCameraRig* was forwarded to the *TrackedAlias*. To get hands that track and behave naturally like the player's hands, the *CustomHand* prefabs were added under the *ControllerAlias* within the *TrackedAlias*. In addition to this, some decisions had to be made for input management and locomotion, which is discussed in the next subsections.

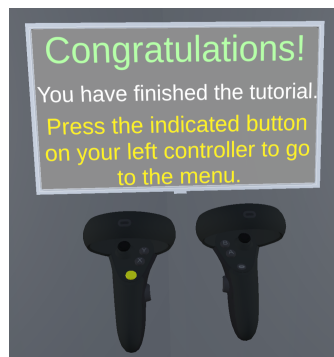
## Controllers

For button mapping, it was decided to follow the standards set by Oculus in the Unity Learn Course [53], which are also used by many VR games. This decision was done to save time on decision making and to avoid potential conflict with the mental model of some users. The chosen button mappings are visualized in Figure 4.1.



**Figure 4.1:** The chosen controller button mapping

Some games map grabbing to the trigger button, but following the Oculus course, it was decided to map this to the middle finger button. One reason for this was to distinguish grabbing and "shooting" actions since some users relate the index finger trigger with the shooting. From the evaluation in Phase 1, we knew that some users were confused by the in-game menu button. As an attempt to avoid further confusion, it was mapped to the left controller menu button like in the Oculus VR course and visualized in the tutorial. The left menu button is leveled with the controller surface, which makes it less tempting to press than other buttons during gameplay.

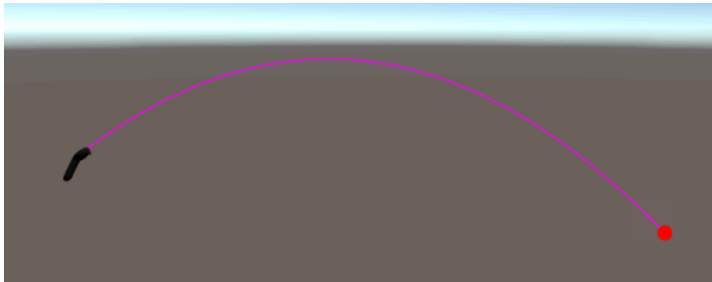


**Figure 4.2:** Clear visual representation of the menu button

## Locomotion

One of the hardest decisions when setting up VR for a new project is to decide which type of locomotion to use or to put enough resources into providing alternatives. Locomotion in a VR application refers to the ability to move. This can be implemented in different ways, where some are considered more comfortable than others. Making the wrong choice may lead to motion sickness and other kinds of discomfort. Many users in the target audience were believed to be new to VR, which makes comfort extra important.

The most popular and comfortable type of locomotion is teleportation. Teleportation is when the player points to indicate a spot on the floor he wants to move to and is automatically moved there. There exist multiple forms of teleportation, but the simplest one is the static Bézier curve for arc teleportation [58], which is illustrated in Figure 4.3. Implementing teleportation is quite advanced, but VRTK comes with prefabs and other resources for setting it up in a meaningful way.



**Figure 4.3:** Parabolic teleport curve

Teleportation was implemented so that when the player touches the joystick, the in-game hand sends out a parabolic curve. The curve checks for any collisions on its way (see Figure 4.3). If the curve collides with a valid surface, the player can press down the joystick button, which makes the screen rapidly fade, and the player appears at the desired location in a few milliseconds.

## Building Room Layouts / Level Design

The quality of the visual work in a game is an essential part of the end user's experience. Since art creation and 3D-modeling is a time-consuming process, it was decided only to use free online resources. An efficient way to make the room layouts look interesting is by using Unity Snaps [59]. Unity Snaps are asset packs that provide assets for building room structures easily with the Unity ProBuilder. Other 3D-models were imported and added throughout the rooms to make them look interesting and to enable spatial memory since that, as discussed in the evaluation of Phase 1 in section 6.1. Two types of doors were animated and reused in different tasks to let the user progress.

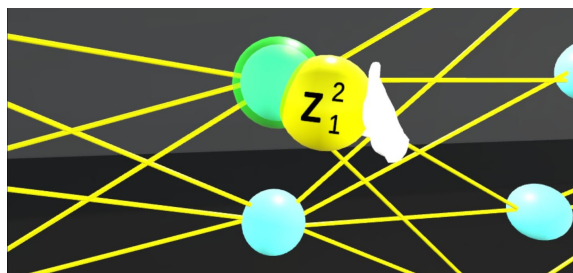


**Figure 4.4:** The green lines in the image shows the teleportable area of the room

To avoid the user from teleporting to an unintended place, a rule for limiting teleportation to objects in the "Teleportable" layer was added. The layer was added to an invisible cube element on the floor, placed 1 meter from the walls of the room. It avoided users from teleporting too close to and ending up inside walls (see Figure 4.4).

### Interactable objects

Every interactable object was implemented using the VRTK *Interactable Primary Grab Secondary Swap* prefab. Using the prefab saved large amounts of time since an interactable object could be set up by simply swapping the default prefab mesh with a custom object. The *Precision Point Grab Offset* was used to avoid spending large amounts of time defining hand offset while grabbing an item. This makes grabbed objects stay in the position they are grabbed, instead of manually defining a natural grab offset for each object and each hand.



**Figure 4.5:** Interactable object and snap zone

A light-blue color was used in most tasks to indicate that the object can be placed there,

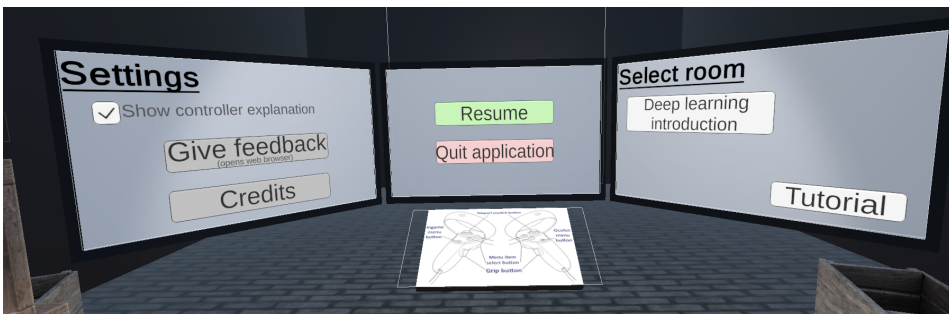
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to let the user intuitively understand where to place an object (see Figure 4.5). VRTK *InteractableSnapZone* prefab was used to highlight that the object is within the range of placement. When the user releases the object, it will naturally snap to the highlighted zone. In Figure 4.5, you see that the object is within range of the top neuron, but not the one below.

The *Interactable Primary Grab Secondary Swap* and *InteractableSnapZone* prefabs come with a set of built-in events, that are triggered upon certain actions. The events were used to trigger events in other objects or functions in scripts, which was convenient for more efficient development through the Unity Editor.

## Menu



**Figure 4.6:** Menu with all three screens

The menu was designed with extensibility in mind, so that new features and new Scenes with new topics can be added at a later stage. The menu was divided into three screens (see Figure 4.6):

- **Left screen:** The intentions with the screen were to add settings like a selection for locomotion type, audio, and a credits button, to credit for every free resource used in the project. Adding different locomotion types was down-prioritized so that that time could be spent on things more related to the research questions. Due to the changes in plans for user testing, a solution for feedback was added to the screen (read section 4.3.10).
- **Middle screen:** Contains the necessary options for the current game.
- **Right screen:** For Scene selection. It can easily be expanded with selections for new rooms with new topics at a later stage, so the application can be used to teach a full deep learning course.

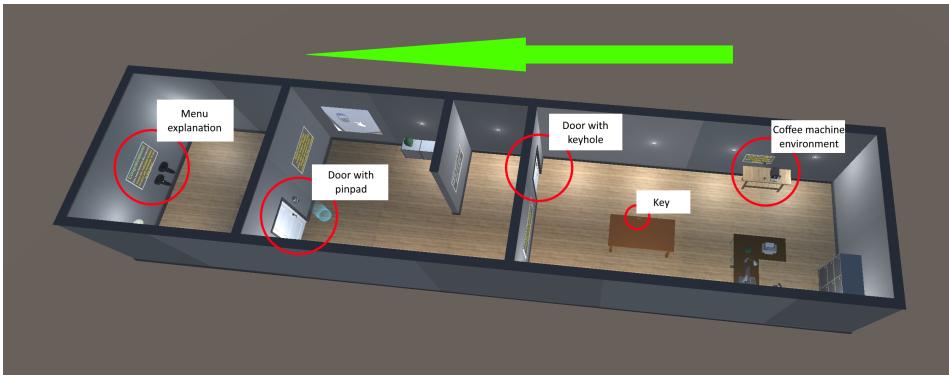
### 4.3.2 Tutorial

Having a good tutorial is crucial for new users, so a fair amount of time was spent planning and implementing it.

## Design

It was decided to use a similar environment as in the rest of the application. The user is required to teleport around the room to complete tasks. Tasks should be placed sequentially through the rooms to make the user learn teleportation for progressing early.

As a basis for the tutorial, the sequence of actions in Table 4.4 were worked out. The sequence of actions is the same as the user goes through, but contains the necessary details for implementation. The table contains mappings to the functional requirements, where the most relevant are emphasized. Figure 4.7 reflects the sequence of events in the table, viewed from right to left. The figure is a screenshot taken in the bird-perspective of the final tutorial.



**Figure 4.7:** Tutorial environment with descriptive texts

#	Description	Related FR
1	When the user opens the application, he appears in front of a table with a coffee cup, a coffee machine, and a TV.	-
2	The first thing the user should see is a TV with a yellow text, telling him to grab a coffee cup. An Oculus Touch controller is placed next to it, indicating which button to press.	<b>T-FR1</b> , T-FR7
3	When the user has grabbed the coffee cup, a new text tells him to place the coffee cup in the coffee machine. A green snap zone lights up when the cup is close enough to the desired position.	<b>T-FR2</b>
4	After the user places the cup, he is told to turn away from the table, where a new TV describes how to teleport. An animation should show how this is done.	<b>T-FR3</b> , T-FR7
5	The user is tasked to unlock a door using a key to proceed. This makes him intuitively learn to teleport while holding an item.	<b>T-FR4</b>

6	In the new room, the user is taught how to interact with a physical UI that opens a door. The user needs to explore the room to find the code.	<b>T-FR5</b>
7	In the final room of the tutorial, the user should be taught how to navigate to the game menu. An Oculus Touch controller indicates which button to press.	T-FR7
8	In the menu, a poster with a controller explanation shows every button the user can press. From this, the user should be able to understand how to interact with the menu.	<b>T-FR6</b>

**Table 4.4:** Tutorial - Sequence of events

### Implementation

The tutorial was developed iteratively since newer and better solutions were discovered through conducting minor user tests. A video showing the resulting tutorial is presented in Table 5.2.

Figure 4.7 shows the implemented tutorial from bird-perspective. The list below explains what was implemented, following the order of the elements in Table 4.4. An overall "ObjectiveHandler" script was used to manage the progress of the player through the tutorial, to display the correct task texts and objects at the right time.



**Figure 4.8:** Grabbing coffee cup and holding it near a snap zone

1. The VR player is instantiated in the Scene.
2. An interactable coffee cup prefab was implemented. A script was used to make sure that the coffee cup was not dropped on the floor or lost. If it moves too far away, a new coffee cup is instantiated.
3. The user is taught to place the coffee cup (see Figure 4.8).
4. To teach the user teleportation, it is done in the order; activate and select. The user is told to touch the joystick, which activates the teleportation curve. When the player

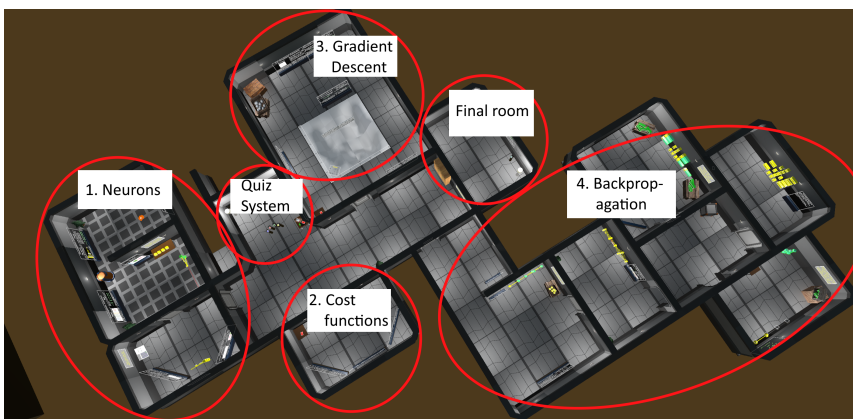
has pointed at a teleportation target placed on the floor, the next step is to press down the joystick to teleport. No animation showing the controller was implemented but could improve the tutorial.

5. Next to the teleportation target, the key is placed. The player can grab the key, teleport, and insert it in the door. An animation plays to open the door.
6. A numpad was placed on the wall. The numpad was implemented using the VRTK *DirectionalJointDrive* prefab on each number, which inputs one number when the button is pressed a certain distance. A *NumpadLogic* manager-script handles input, displays it, and opens the next door when the code is right. The player is taught to interact with the numpad, reading the task description. When conducting minor user tests, some people had problems fully understanding the interaction. Therefore, a short video was added to show how to interact with the numpad.
7. In the final room, the user is taught to navigate to the menu (see Figure 4.2).
8. See subsection 4.3.1, for the menu implementation.

### 4.3.3 Deep Learning Introduction

This section gives an overview of the level design of the deep learning introduction Scene. The next sections describe what was designed and implemented for the Scene. Not every task is covered in the sections since some of them shared the same concepts for implementation, but they can be viewed in the resulting videos in Table 5.2.

The final level design of the deep learning introduction Scene ended up having the planned sequential introduction of topics. The numbers in Figure 4.9 shows the sequence of topics. The user finds a cartridge loaded with a quiz within each topic's room that he needs to complete using the quiz system to reach the final room. Since backpropagation is a quite complex topic, it was divided into multiple rooms, as an attempt to introduce the topic piece by piece, leaving the complex maths to the end.



**Figure 4.9:** Bird-perspective level design of the deep learning introduction Scene

### 4.3.4 Learning Material

#### Design

Within each room, it was planned to give an intuitive sequence of learning materials, using these types of learning materials:

- Panels with text and images
- Audio voice-overs that explain a certain subject or guide the user
- Videos
- 3D-visualizations
- Combinations of the above

#### Implementation

Creating learning materials for the project's application turned out to be a very time-consuming process. Without much previous knowledge in deep learning or pedagogy, an intensive amount of work was put into getting a deeper understanding of the curriculum and finding meaningful ways of presenting it in VR. The application ended up having a high amount of text panels, which is not optimal for the user's comfort and engagement. With the right amount of resources, it should be possible to make a much more immersive and engaging experience by replacing and applying text panels' contents in other types of learning materials.

A prefab for text panels was made to make new learning materials efficiently. The text panels were the main type of learning material used and consisted of the elements listed below. The other types of learning materials used are presented in the next sections since some of them were also used for tasks, and the design and implementation of gradient descent was quite complex.

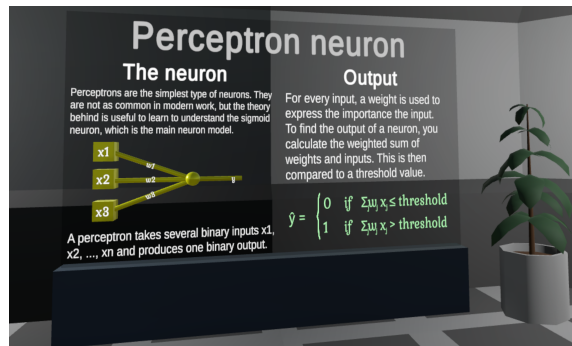


Figure 4.10: Example learning material

- Each panel had a title stating the current room's topic.

- The panel had two "sub-pages" with content. Some panels were half the size of the panel in Figure 4.10.
- Formulas and anything math-related was emphasized with another font and color, to improve readability and make the panel more interesting.
- Some 3D representations were used, like the neuron in Figure 4.10.
- Many panels included ".png" or ".jpeg" images. The quality of images are scaled down on the Oculus Quest and requires the player to stand within a close range to see it properly. No good solution to the problem was found, so it was attempted to keep the number of images low.

### 4.3.5 Gradient Descent Visualization

One of the more promising concepts for really utilizing the VR technology was through visualization of Gradient Descent.

It was decided to find a way to visualize the surface of a cost function in 3D and use it to explain how the cost is minimized using Gradient Descent. The design was drafted with inspiration from Michael A. Nielsen's book on Neural Networks [32] and 3Blue1Brown's series on Deep Learning on YouTube [6]. Figure 4.11 shows how the surface of a cost function with two input parameters is visualized above a coordinate system, where the axes represent the inputs of the cost function.

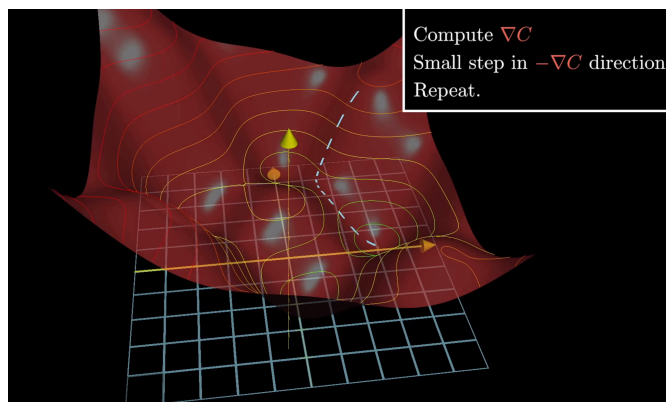


Figure 4.11: Gradient Descent visualized by 3Blue1Brown [6]

Multiple alternatives with highly varying underlying complexity were considered for implementation. The final decision was made through trial-and-failure at the time of development. The different alternatives are considered below.

#### Design

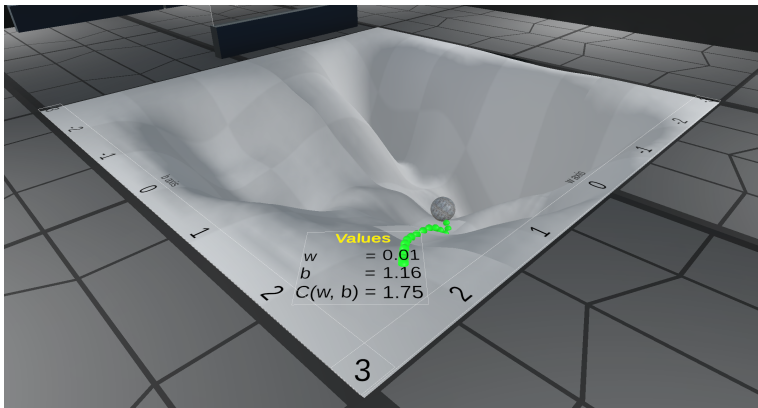
The visualization consisted of two parts:

1. **Visualizing a Cost Function surface:** It was decided to visualize the cost function as a terrain. It could be done in two ways, where the first way would have a much simpler implementation, and the second one would visualize a more precise and adjustable cost function. The user can perceive the depth of the terrain since he sees it in 3D. However, it was also planned to use a gradient color to distinguish the surface's depths easily.
  - **Terrain builder tool:** By using the built-in tool, a near visual representation of a cost function could efficiently be developed by manually raising and lowering the terrain using the tool. It would also automatically generate a collider for the surface. The visualization would not be precise, but probably be feasible to explain the concept.
  - **Plotting the function mathematically:** Some sources for plotting mathematical surfaces in Unity were found [60]. The solution would give an exact representation of the function and also allow for plotting new cost functions during run-time.
2. **Execution of Gradient Descent:** To visualize execution, it was decided to repeatedly initialize a ball at random points of the surface of the terrain. The ball then moves downhill, leaving a trajectory until it reaches some minimum and can be initialized somewhere else. The algorithm itself uses the partial derivatives of the current point to find the steepest decrease of the cost function, and it then takes a step of a certain size in that direction. It was considered to calculate this using code and then let it move in this direction using different step sizes to demonstrate what might happen if this value is too low or too high. An alternative to this was to use the built-in physics to make the ball move downhill using gravity. The *Rigidbody* values of the ball object for "Drag" and "Angular Drag" were considered to resemble different step sizes.

## Implementation

It was attempted to implement the most complex alternatives of implementation from Section 4.3.5. The first step of implementation was to create a terrain to represent the surface of the cost function. Attempts of plotting the cost function were made, but as time elapsed developing, it was hard to justify the advantages of doing this, compared to simply resembling a cost function surface using the built-in terrain builder tools. With the end-user in mind, the final goal of the feature was to understand the concept of Gradient Descent. The final terrain was shaped in a way that included multiple local minimums, as well as the possibility to find paths where local minimums are skipped on the path to the global minimum. See Figure 4.12.

After shaping the terrain, it was time to add a gradient color to color the terrain based on height. Plenty of time was spent trying to implement this, but near to completion of the functionality, it was discovered that it was required to change the render pipeline of Unity. After attempting to change the render pipeline, multiple models lacked textures, and the VR setup stopped working. The project was reverted to the point before implementing this. Due to the limited time of the project, it was concluded that with the perception of



**Figure 4.12:** Gradient Descent implementation

depth in VR, lights, and shadows, the user is still clearly able to see the differences in depth of the surface.

As for the implementation of the ball, it was attempted to use the built-in physics of Unity to see if adjustments of "Drag" and "Angular Drag" were an adequate solution of resembling step size. The solution proved to be sufficient and time-saving. In the code, five predefined points of the surface, for initializing the ball was added. During runtime, the ball initializes at the first of these points. It moves with gravity and is assumed to have reached some minimum when the velocity is lower than a certain threshold. Then, the ball is removed, and it is initialized at the next location. For every 200ms the ball moves, a small sphere is initialized at the position of the ball, which leaves a dotted trail, visualizing the ball's trajectory.

### 4.3.6 3D Visualizations of Neural Networks

#### Design

Models of connected nodes and edges are often used to teach neural networks. Visualizing this in 3D would remain conceptually the same, but could make learning more engaging. The plan was to represent the models using cubes for inputs, spheres for neurons, and cylinders for connections in both tasks and learning materials.

#### Implementation

Multiple tasks and learning materials used the same principles as the one in Figure 4.13. The example shows a task where the user is taught neural network notation by correctly placing neurons to open the next room.

Implementing these tasks are fairly straight-forward, but doing so demands a lot of time doing manual and repetitive work. The author truly believes that this type of task has more potential if a more easily reusable solution is designed. One example is to find a



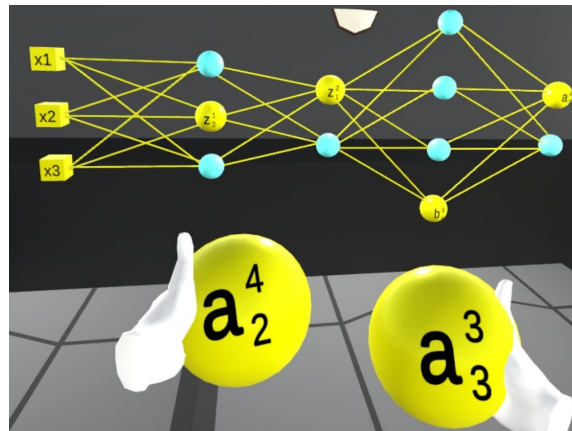


Figure 4.13: Neural Network notation task

way to automatically create these tasks through code. For every task of this type, these prerequisites were needed:

- Everything needs to be set up in the 3D space
- A prefab is made for each interactable element. The prefabs need a script that reveals the prefab instantiation's variables to the Unity editor so that each instantiation's values can be set correctly. Ex. for neural network notation, a value for layer and index is needed.
- An overall manager-script handles the game-flow of the task.
- A snap zone needs to be defined for each position an object can be placed. Each snap zone must forward the inserted object's values to the manager-script.

### 4.3.7 3D Visualizations of Formulas

#### Design

One of the core problems of the tasks for building formulas in the application from Phase 1, was that the text elements were too closely placed and that picking up text was not intuitive. Some users mentioned that the tasks were still useful for learning since they made the formulas feel more real than on paper. As an attempt to solve the problems, it was decided to utilize VR more by creating 3D-puzzles of these tasks.

#### Implementation

Tasks for building formulas were planned and implemented using the same principles as for the neural networks presented in section 4.3.6.

### 4.3.8 Activation Function Calculator

#### Design

Since the user is fully immersed in VR and cannot use regular tools for doing calculations, it was decided to create dedicated in-game calculators that can be used for solving tasks. Calculating the output of an activation function is too complicated for mental arithmetic. It was decided to have an activation function calculator accessible for the sigmoid neuron task.

#### Implementation

The calculator ended up being used for sigmoid activation function calculations only but was implemented with reusability in mind. It was implemented, showing that the user's input is the weighted sum  $z$  (see Figure 4.14). The interface of the calculator was built on top of a canvas. Colliders were used on each number to check for input. Optimally, the calculator should have physical joints for buttons like the numpad described in subsection 4.3.2, but this was not implemented due to a lack of time.

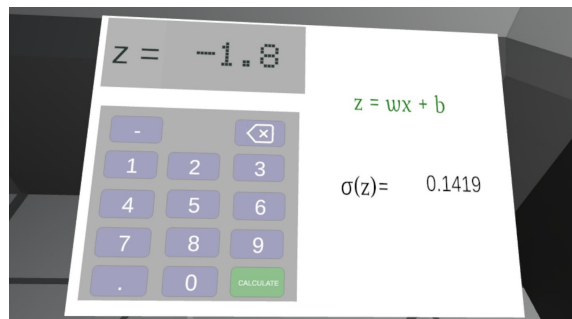


Figure 4.14: Sigmoid function calculator

### 4.3.9 Quiz System

In escape rooms, players are often required to solve a set of tasks and combine their results to progress. The concept of the quiz system was to make users find cartridges loaded with quizzes while progressing through topics. The user needs to win each quiz and place the cartridges together to complete the application. A thorough design was planned and implemented.

#### Design

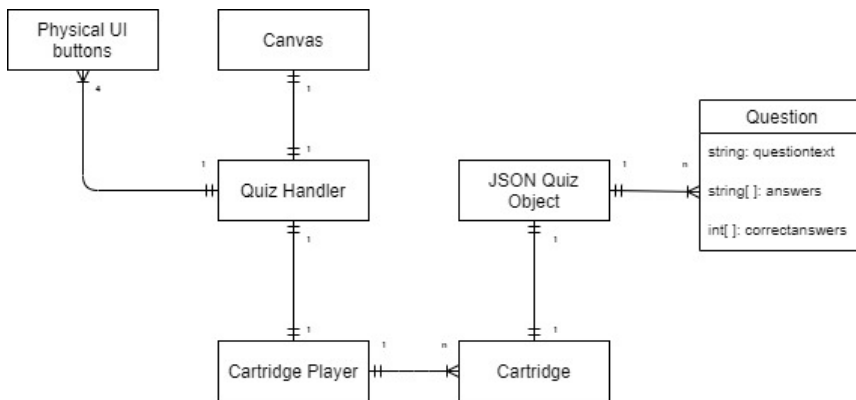
The multiple-choice questions from Phase 1 worked well. New ideas for how to make the quiz more engaging were drafted. It was decided to split the quiz into a small series of questions for each topic, to balance time spent learning and doing tasks. It was also decided to integrate more interactive 3D elements in the quizzes to increase motivation for doing this type of task in VR.

*Elements of the quiz system:*

Figure 4.16 shows the quiz system.

- **Quiz System Area:** This is the area the user is led to after learning about neurons. A manual explains how the quiz works, but it should be intuitive enough to use without reading it.
- **Cartridge Player:** In the Quiz System Area, a cartridge player is placed next to a projector. This indicates that what the user puts into the cartridge player, will be displayed on the screen next to it.
- **Cartridges:** For each topic, there is a cartridge. Cartridges are inserted in the cartridge player. Each cartridge contains a quiz that is displayed on the big screen in the quiz system area. The user completes the cartridge by answering correctly on most questions. The cartridge will then turn green to indicate that it is completed, and the user can proceed to the next topic.
- **Physical buttons:** When a cartridge is inserted, physical buttons will appear on the floor in front of the big screen. The user interacts with the buttons to respond to the questions.

Implementing new tasks and interactions in VR can be a time-consuming process. The quiz system was designed to be easily extendable with new quizzes, to facilitate the architectural quality attribute extensibility. The quiz system was carefully planned and is illustrated in a simple ER model in Figure 4.15.



**Figure 4.15:** Simplified ER model of the quiz system

While designing the quiz system, inspiration was drawn from the MVC (Model-View-Controller) design pattern [61] to enable modifiability. In Figure 4.15, think of the Physical buttons and Canvas as the View. The View is what the user sees and interacts with. The Quiz Handler and cartridge player together is the Controller, since the Quiz Handler handles user input and quiz progress, while the cartridge player fetches the quiz and forwards it to the Quiz Handler. Each cartridge parses data from the JSON Quiz Object into C# list elements and provides the necessary data for the current quiz (Model).

To keep a fair balance of learning and doing tasks, it was decided to keep the number of questions for each quiz low (3-8 questions per quiz). The decision to use cartridges and physical buttons were made with hope for engaging the user since he needs to bring the cartridges to complete the overlying tasks of the escape room. The physical buttons were added as an attempt to give a more immersive experience, instead of interacting with a 2D screen. The final design of the quiz system (see Figure 4.16) was made with inspiration from games like BUZZ! [62] and Kahoot [63].

### Implementation

The implementation turned out to be one of the more complex implementations of the application. It required a high level of extensibility, modifiability, and usability.

The first step was to implement cartridges so that they could parse JSON data into C# objects. A NuGet package was imported to Visual Studio, and all necessary code for parsing JSON data was written, but this did not work in Unity. That was because Unity is running on an older version of Mono and since Unity generates its Visual Studio solution, which wipes out any NuGet packages [64]. The problem was solved by importing *JSON .NET For Unity* from the Asset Store. After that, the JSON reader was set up to correctly read the JSON files from the correct path on both Android (Oculus Quest) and Windows/Mac.

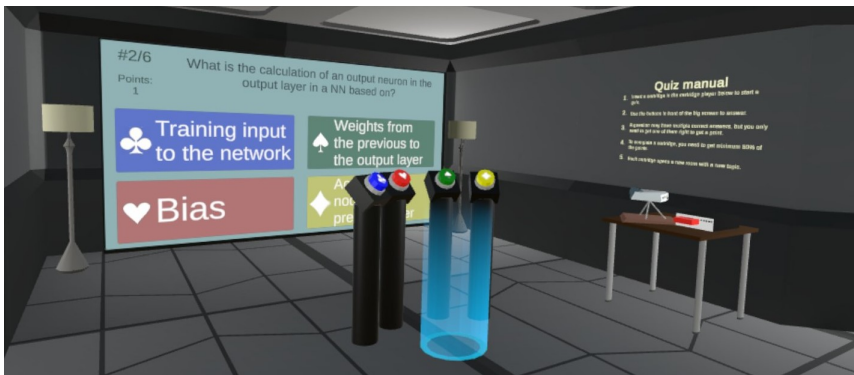
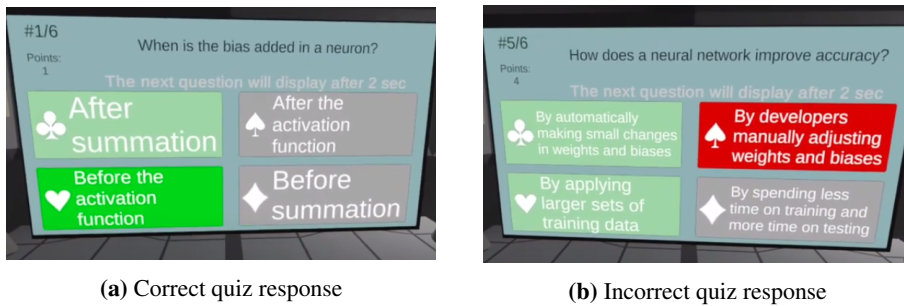


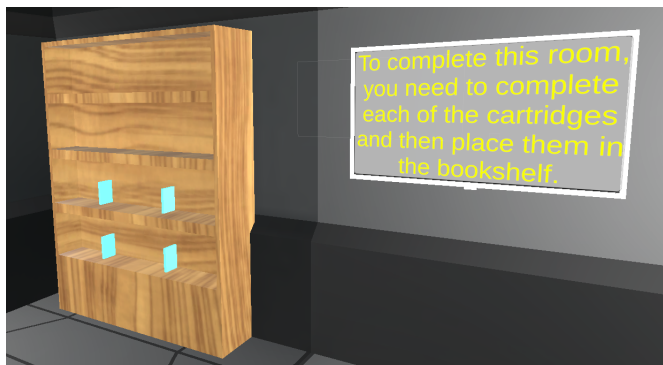
Figure 4.16: Quiz system with inserted cartridge

The second step was to set up the canvas and models in the Scene, like in Figure 4.16. A script was written to handle the quiz game flow. When a user responds to the quiz, a new view gives feedback on the response's correctness (see Figure 4.17). A strong color shows if the user's response was correct or not. Since some questions had multiple correct answers, these were indicated with a weaker green color. The first version had no sound effects, but this was added after minor user tests to follow Don Norman's design principle for feedback [30, chap. 1]. In the initial design, the user was meant to press any button again to go to the next question. During the minor user tests, some users did not find it intuitive to press the same buttons to proceed, since the interaction was confused with responding to the quiz. The answer feedback was instead shown for 2 seconds before going to the next question, to improve the affordance of the physical buttons.



**Figure 4.17:** Quiz response feedback

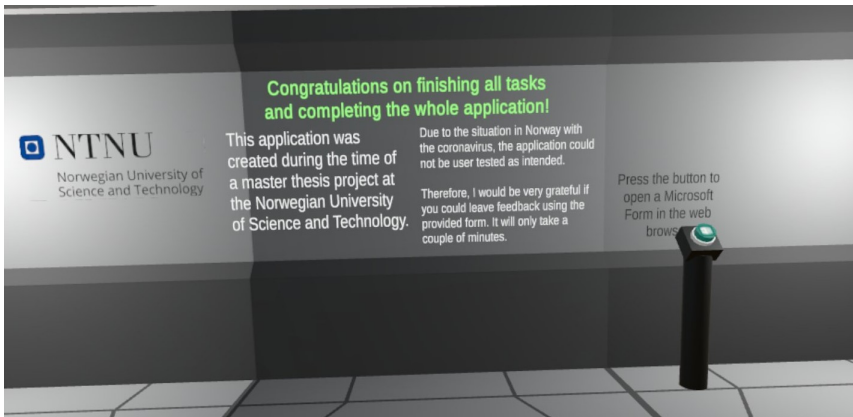
Finally, a threshold for the minimum amount of correct answers was set. It was set to a minimum of 80%, to make users retry if the score was too low, but not lose motivation if only one answer were wrong. A bookshelf was placed with one spot for each cartridge to indicate the application's final goal (see Figure 4.18).



**Figure 4.18:** Bookshelf indicating the final goal of the application

### 4.3.10 Solution for Online Evaluation

The application was planned to be published on Reddit, hoping for random people online to user test it. An alternative solution for submitting feedback was implemented to ensure that people played the application before giving feedback. See the video showing the solution in section 5.2.1. The thoughts around online user testing are presented in section 3.4.2.



**Figure 4.19:** Screenshot of the final room of the application where users could leave feedback

After the user has finished every quiz cartridge in the application and has placed them in the bookshelf, he can enter the final room. There, the user is thanked for his efforts and requested to press a button to fill out a form (see Figure 4.19). Unity comes with the built-in function *Application.OpenURL(param)* that automatically opens a link in the Oculus Quest web browser. The function was used to open the Microsoft Form questionnaire presented in section C.2.1. A button was also added to the game menu for users who do not want to play through everything.

### 4.3.11 Optimizing the application

As the main Scene grew in size, some performance issues became noticeable. The frame rate on the Oculus Quest dropped down to somewhere between 30 and 40 FPS at certain places of the application. The problem was unforeseen since the graphical work of the application was thought to be kept simple enough to maintain a good performance. When the application was published on Reddit, a user mentioned that he experienced discomfort in the later stages of the application. The low performance made reading texts uncomfortable, which made him skim through the learning materials. It was decided to put some efforts into optimization, to avoid performance issues from influencing the general feedback.

#### Causes of performance issues

The application was analyzed using the Unity Profiler tool. These are the main elements that caused lower performance:

- With a large Scene, consisting of multiple rooms, many objects are drawn in every single frame, even though the user can see not all of them.
- TextMeshPro is computationally demanding. A large number of canvases using TextMeshPro was drawn in each frame.

- The version of VRTK Prefabs had some performance issues while grabbing and moving objects. This problem was amplified by the TextMeshPro drawn on top of the objects.
- The lighting of the Scene was mainly dynamic and calculated in real-time, which was computationally demanding.

### Mitigating the performance issues

It was decided to put some effort into mitigating the problems. Achieving the recommended stable 72 FPS was considered to require too much time, but the optimizations mentioned in the list below increased the performance to rarely go below 50-60 FPS, which was deemed to be adequate for the prototype.

- The project settings and graphic quality were reduced following a guide from Oculus [65].
- *GPU Instancing* was enabled for every material used.
- The *Static* option was enabled on every room structure model, prop, and learning material. The Scene could then be baked with **Occlusion culling** [66]. Occlusion culling is when an object is not rendered because another object obscures it. It had a large impact on performance since the TextMeshPro canvases were not drawn unnecessarily.
- The lights were baked into texture maps for every Static element in the Scene [67].





# Chapter 5

## Results

This chapter gives an overview of the application used for evaluation in Phase 1 and the application developed in Phase 2. The evaluation results from both phases are also presented and will be analyzed and discussed in chapter 6. The Phase 1 application was developed by Håvard Snarby and is included here because the evaluation results built the foundation for the main part of the project, Phase 2. The author developed the Phase 2 application. Read more about the project's phases in section 3.2.

### 5.1 Phase 1

This section presents the application developed by Håvard Snarby, and the results from the evaluation where the author played a key role in planning and execution of user tests.

#### 5.1.1 The Application

##### Concept

The user starts in a room, where learning materials are placed on panels, walls and grabbable notes. Different types of tasks appear on a table in the middle of the room, and the user needs to solve every task to complete the room. It is up to the user to figure out how to apply the available learning materials. When the user has fulfilled every task in a room, his performance is displayed on the screen. Then, the user can progress to the next room. One of the main goals of this application was to design tasks that are highly reusable and extendable.

##### Videos

The concept remains the same throughout the different rooms of the application. Therefore, it should be sufficient to watch the videos for the tutorial, room 1, and room 4, to

understand the concept and get an overview of the application.

Video	Link
Tutorial	<a href="https://youtu.be/7VoMdXFvREU">https://youtu.be/7VoMdXFvREU</a>
Room 1	<a href="https://youtu.be/CGtAkvczDE">https://youtu.be/CGtAkvczDE</a>
Room 2	<a href="https://youtu.be/63FUpjTQnzw">https://youtu.be/63FUpjTQnzw</a>
Room 3	<a href="https://youtu.be/_OaL3RIRCqM">https://youtu.be/_OaL3RIRCqM</a>
Room 4	<a href="https://youtu.be/85AybSk4WGs">https://youtu.be/85AybSk4WGs</a>

**Table 5.1:** Videos of the Phase 1 application

### 5.1.2 Evaluation

This section presents the results of the user tests conducted through week 4, 2020. All users played through most of the content.

#### Evaluation Participants

The user tests were conducted by 12 voluntary students from the course "*TDT4265 - Computer Vision and Deep Learning*". 10 users responded to the questionnaire. From Figure 5.1, we see that their experience with VR was generally low. Seven users were interviewed, where two of them did not respond to the questionnaire. One of the two was highly skilled in VR development, which led to some valuable insight. The users had a varying level of competence in deep learning.

#### Interviews

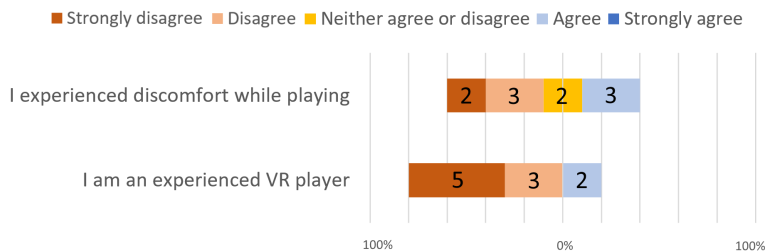
Even with only seven interviews, the amount of feedback received was quite high. Therefore, the interview feedback has been structured and moved to Appendix C.1.2. The key findings are briefly presented below and are further discussed in section 6.1.2.

- **Concept:** The users saw potential in the concept, even though more resources should be put into development.
- **Tasks:** The users were satisfied with some of the tasks where 3D-elements were introduced. However, the tasks got highly repetitive and did not justify the use of VR since they were solved on a 2D screen in the middle of the room. This led to impatience.
- **Learning material:** Just like for tasks, the learning material did not justify the use of VR, due to a lack of 3D elements. Also, they were arranged somewhat randomly through the room, which led to confusion for some users.
- **Escape room elements:** All users were interested in introducing puzzles, abstractions, and other game elements to the application.

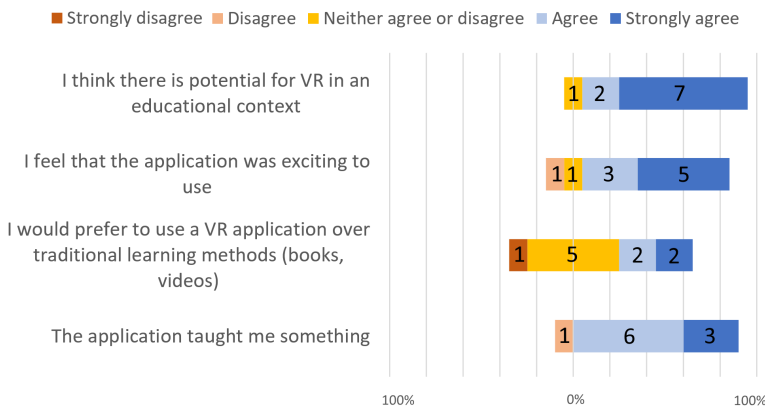
## Questionnaire

10 users responded to the questionnaire. The results are presented as Diverging Stacked Bar charts [68] in Figure 5.1 and Figure 5.2. The vertical axis represents the various statements, and the horizontal axis represents the total number of participants on both the positive and negative side of the scale. The number on a bar represents the accumulated amount of people with a certain response. Keep in mind that a positive response is not necessarily on the right side of the scale.

By UIUX Trend's method of calculating the System Usability Scale (SUS) score [69], the results from Figure C.1 gives an average score of 75.5. This is a grade B, which is considered good. The responses to the SUS schema have been moved to Appendix Figure C.1.



**Figure 5.1:** Phase 1 user test results - Discomfort and experience



**Figure 5.2:** Phase 1 user test results - Learning and engagement

## Observations

Some observations were made. Since the interviews covered the same topics, the observations have been merged into the interview data. One interesting finding from the observations was how differently the participants used the grabbable learning material notes.

Some of them arranged them well and used them actively, while others barely touched them.

## 5.2 Phase 2

This section presents the application developed by the author in Phase 2. Then, the section presents the results from both evaluation types conducted online. Alternative ways of evaluating the application were planned and conducted, due to the Covid-19 situation, as described in section 3.4.2.

### 5.2.1 The Prototype Application

The application is considered a prototype, since there is still more work to do. Read chapter 4 for details on how the application was implemented. It is recommended to play through the application to get the full experience. Alternatively, the videos below should give a good overview.

#### Play through the application

Go to the link provided below to download the application. The application has been built to work on Oculus Quest, Rift, and Rift S to reach out to as many people as possible, even though it is mainly intended for the Oculus Quest. Installation guides are provided for all devices. Playing through the whole application should take approximately 30-90 min, depending on the user's experience with VR and deep learning.

<https://drive.google.com/drive/folders/1gYGsX95d3tFXyZE2iuZ6CZ1LorzNztE>

#### Videos

The first video in Table 5.2 efficiently gives an overview of the whole application by explaining the core concepts with a voice-over. The second video is a more lengthy playthrough video that covers all the content of the application. Use the timestamps in the video descriptions to view specific parts of the application.

Video	Link
Concepts with voice-over	<a href="https://youtu.be/Tv1N-dxAn4M">https://youtu.be/Tv1N-dxAn4M</a>
Full playthrough	<a href="https://youtu.be/Mfcauuc-pD8">https://youtu.be/Mfcauuc-pD8</a>
Tutorial	<a href="https://youtu.be/w62h4PyNVGA">https://youtu.be/w62h4PyNVGA</a>
Online feedback solution	<a href="https://youtu.be/JnsGbGTD-Gk">https://youtu.be/JnsGbGTD-Gk</a>

Table 5.2: Videos of the Phase 2 application

### 5.2.2 Online User Test Evaluation

The online user test evaluation started on April 12 and lasted until the end of May 2020. The subsections below describe the participants that were reached out to before presenting

the results. In total 15 users tested the whole application. 9 of the participants were from one of the subreddits or the IMTEL network. 6 of the participants were from the author's student housing.

## Evaluation Participants

Multiple attempts were made to reach out to users. In the first attempt of reaching out, a post was written in the subreddit *r/OculusQuest* [70]. The attempt led to four questionnaire responses and some more detailed feedback in the comment section. One user mentioned some uncomfortable performance issues, so a few minor bugs were fixed, and the application was optimized (see section subsection 4.3.11). As an attempt to reach out to more people, the new version was built for Oculus Rift/Rift S as well, and posted in *r/oculus* [71]. In the same period, user testing in the IMTEL network [56] started.

The author lived in a large student-housing of 116 residents with multiple computer-science students. Five people from the household participated in the user tests. All of the students were in the 3rd to 5th year of computer science. Two of the students were taking the course *"TDT4265 - Computer Vision and Deep Learning"*, and one of them had participated in the Phase 1 user tests. Their playthroughs took in average 1 hour.

## Questionnaire

Every user responded to the questionnaire. The results are presented as Diverging Stacked Bar charts [68] in Figure 5.3, Figure 5.4 and Figure 5.5. The vertical axis represents the various statements, and the horizontal axis represents the amount of participants on both the positive and negative side of the scale. The number on a bar represents the accumulated amount of people with a certain response. Keep in mind that a positive response is not necessarily on the right side of the scale.

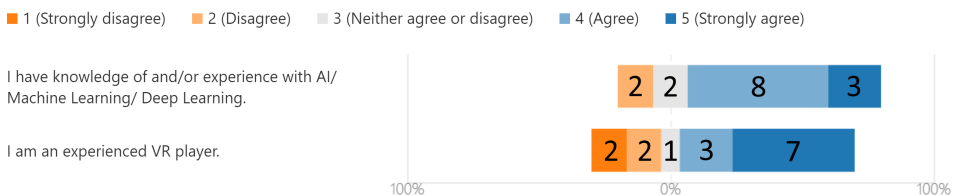
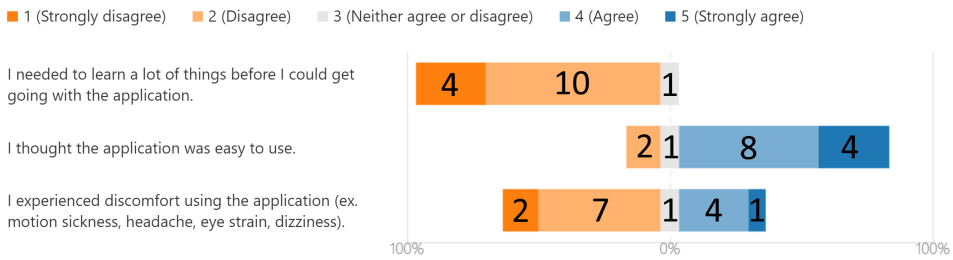
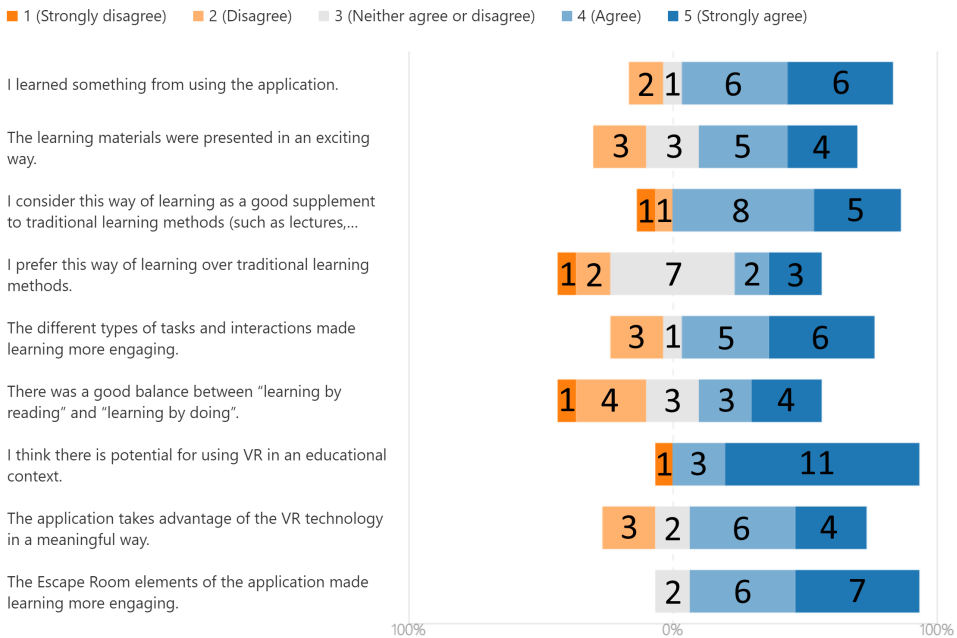


Figure 5.3: Phase 2 online user test results - experience

## Chapter 5. Results



**Figure 5.4:** Phase 2 online user test results - usability



**Figure 5.5:** Phase 2 online user test results - learning and engagement

### Written Feedback

12 out of 15 users submitted written feedback in the questionnaire, and some written feedback was received in the comment section on Reddit. The feedback has been structured and moved to Appendix C.2.3. The key findings are presented below and discussed in section 6.2.2.

- Tasks:** Multiple users stated that they thought the escape room concept was good for learning and enjoyed solving puzzles to progress. The users enjoyed tasks for neurons and neural network notation. However, they ended up solving some of the notation tasks by trial-and-failure, due to a lack of learning material for backpropagation.

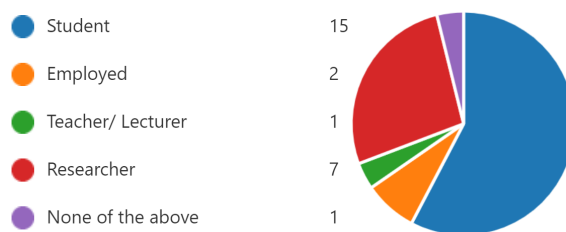
- **Quiz system:** Multiple users enjoyed the quiz system, even though some mentioned that the difficulty could be greater. Some users thought to collect and win cartridges was engaging and rewarding.
- **Learning material:** The users were highly satisfied with the 3D-visualization of gradient descent and the neural networks. However, the high amount of text panels made the experience less immersive and made some users impatient.
- **Topics in different rooms:** One user mentioned that having different rooms was helpful since the learning material was "fed to him in bits" and tested the user along the way.
- **Escape room elements:** Multiple users stated that the escape room elements were good for learning.

### 5.2.3 Video Evaluation

The video evaluation started May 22 and lasted to the end of May 2020. This section describes the attempts made to reach out before presenting the questionnaire results. In total 26 people responded to the questionnaire.

#### Evaluation Participants

The questionnaire was distributed in NTNU's OpenAI and DART research groups [72], students from the course "*TDT4265 - Computer Vision and Deep Learning*", the IMTEL network and the author's fellow students within AI. The questionnaire was also distributed in the subreddits *r/artificial*, *r/ArtificialIntelligence*, *r/OculusQuest*, *r/oculus*, and *r/virtualreality*. See the reference for an example of an attempt to reach out on Reddit [73]. 88% of the participants studied or had previously studied computer science. One of the respondents tested the application. Figure 5.6 shows the roles of the participants.



**Figure 5.6:** Phase 2 video evaluation results - participants

#### Questionnaire

26 people responded to the questionnaire. The results are presented as Diverging Stacked Bar charts [68] in Figure 5.7 and Figure 5.8. The vertical axis represents the various statements, and the horizontal axis represents the total number of participants on both the positive and negative side of the scale. The number on a bar represents the accumulated

amount of people with a certain response. Keep in mind that a positive response is not necessarily on the right side of the scale.

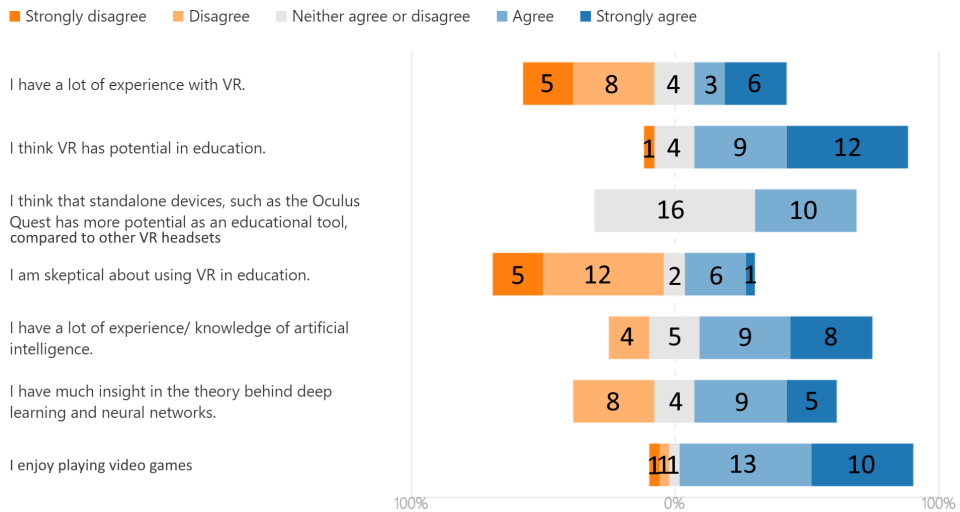


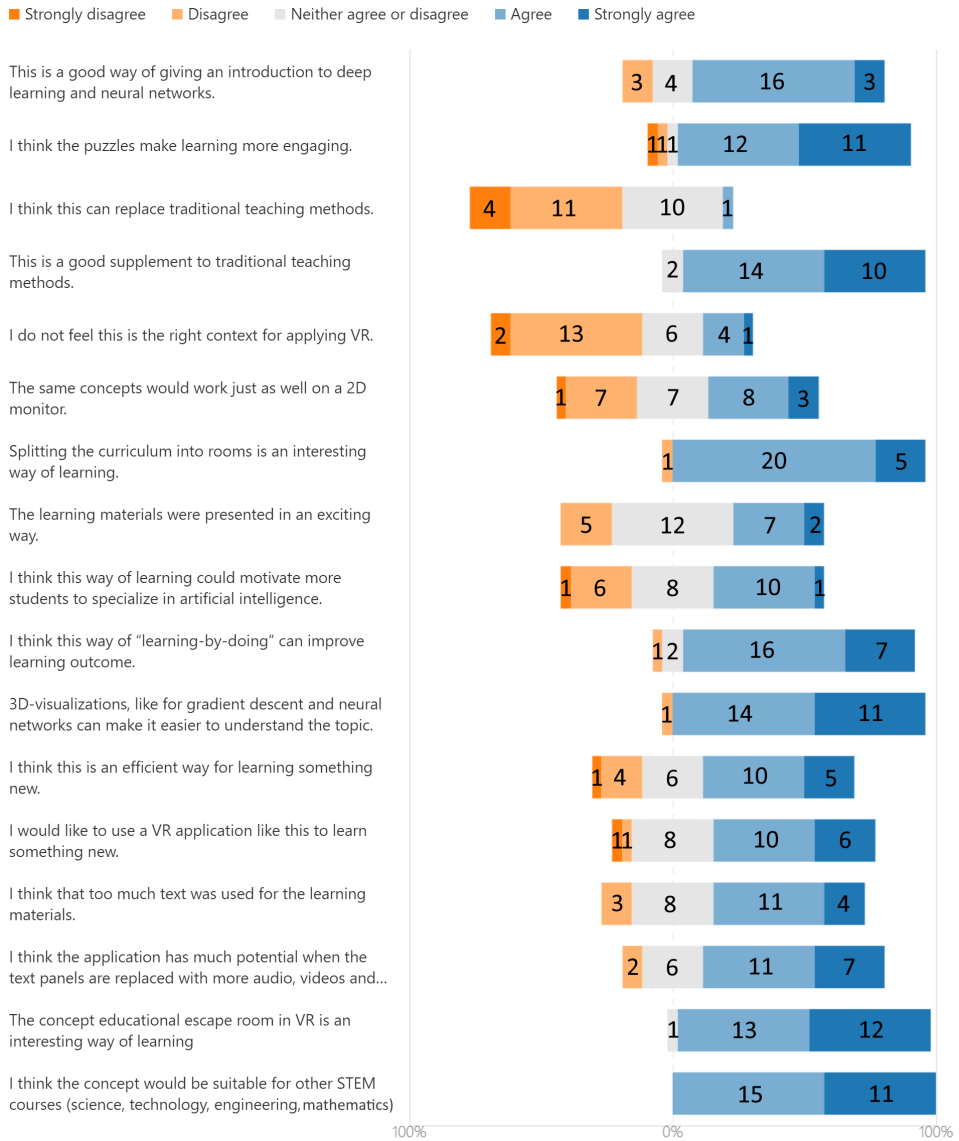
Figure 5.7: Phase 2 video evaluation results - general opinions

### Written Feedback

8 people submitted written feedback. The responses are shown in Appendix section C.2.4 and the key findings briefly presented below and are discussed through section 6.2.

- **3D-visualizations:** One participant mentioned that the main benefit of using VR for teaching AI was through 3D-visualizations.
- **Improvement compared to the Phase 1 application:** One participant tested the first application and thought the puzzles, 3D-interactions, and visualizations were an improvement of the experience.
- **Learning-by-doing:** One participant compared traditional methods with the VR solution. His key point was that doing practical activities based on the course-material was beneficial, but that mass-training with traditional methods would be necessary to understand the curriculum fully.
- **Reading using a technological solution:** One user stated that he does not enjoy reading on a computer screen, and that reading in VR feels even worse.





**Figure 5.8:** Phase 2 video evaluation results - learning and engagement



# Chapter 6

## Discussion

This chapter will discuss the results from the evaluations conducted in Phase 1 and Phase 2, which were presented in chapter 5. Then, the chapter will address whether the requirements for the Phase 2 application were fulfilled or not. In the end, the chapter will attempt to respond to the research questions, and the author will give his reflections on the project and discuss limitations.

### 6.1 Phase 1

Based on the feedback from the questionnaire, interviews, and observations, we realized that using a VR application for giving an introduction to deep learning had much potential. However, to justify the use of VR in this context and increase engagement, much more work would be needed to utilize the VR technology better. The students stated that they learned something from using the application, but got impatient due to highly repetitive tasks and confusion around learning materials. Every interview participant was positive about introducing more escape room elements like puzzles or other game elements to make the learning more engaging.

This section discusses the participants of the user test. Then, the interview feedback will be discussed first, so the opinions on the statements can be seen in context with the interviews.

#### 6.1.1 Evaluation Participants

The 12 people from the course *"TDT4265 - Computer Vision and Deep Learning"* attending was only a small fraction of the total number of students. Thus, it is fair to assume that the user tests may have attracted VR enthusiasts and people more eager to try the technology. Also, since it was the first time of using VR for multiple participants, the "wow"

factor<sup>1</sup> could have been higher, which could have made them more positive to the solution than someone more used to the technology. Although the participants could have reflected the target audience better, the participants' varying knowledge of deep learning and experience with VR was considered somewhat suitable for measuring engagement, usability, and learning. Optimally, the application should have been tested on as many people as possible from the course to gather the opinions of VR skeptics as well, but encouraging this many people to participate is more complicated.

### 6.1.2 Interviews

This section covers the key findings from the interviews. The full structured feedback from the interviews with some reflections can be found in Appendix C.1.2.

From the interview feedback, it seemed like users generally saw potential in the concept, but that there were still much work needed. The students had varying opinions on how the application could best be applied in a course, but most of them thought it would work well for giving an introduction to a topic. As a summary of the interview feedback and reflections, there were three topics worthy of further research:

#### Tasks

For most users, the tasks became highly repetitive and lengthy, making them feel impatient and lose interest in solving tasks properly. Varying in tasks is crucial to avoid users from solving them by trial-and-failure. Despite the problems, users enjoyed the few tasks where 3D-elements were introduced. The other types of tasks worked for teaching the topic to some degree, even though they got repetitive. One solution to this might be to vary more in task types used throughout the application. Also, there was a need to utilize VR technology more by attempting to map 2D tasks to 3D objects and puzzles. However, when abstracting the curriculum into puzzles, it is important to not over-do it, since some users may find this inefficient. Exclusively using a 2D screen in the middle of the room was not the right way of teaching AI in VR, since this could have been done on a monitor.

#### Learning materials

The learning materials were placed somewhat randomly in the rooms, which made them challenging to apply for the users with less prior knowledge in the topic. For users to more intuitively apply the materials, they could be arranged more sequentially. Just like for the tasks, more 3D elements should be applied for the learning materials. For example, a visualization of concepts like neural networks and gradient descent could increase engagement and the room's appeal. Some users mentioned that the learning materials on walls and grabbable notes made it easier to remember information spatially. This shows some of the advantages of applying VR in an educational context. It was looked further into during the literature study (see section 2.3.4), to understand how to utilize spatial memory further.

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<sup>1</sup>Wow factor is the feature of something that makes people feel admiration or excitement. Being fully immersed in a virtual world using VR for the first time is often met with more excitement than for an experienced user.

## Escape Room Elements

Users were very positive about introducing puzzles, abstractions, and gamification to add another layer of gameplay on top of what was being taught. It was considered worthy of exploring how the escape room elements could be mapped to VR, after seeing how educational escape rooms have been successfully applied in other studies (see section 2.3.3). The application had some elements that may remind of an escape room. However, typically, educational escape rooms abstract the topic more into puzzles, to make the experience more engaging and rewarding. Giving the application more of an escape room vibe could also engage users to explore the topic at their own pace.

### 6.1.3 Questionnaire

#### Learning and Engagement

The responses to the statements presented in Figure 5.2 are discussed in this section. Each statement has been given an average score, where strongly disagree counts as 1 and strongly agree counts as 5.

*I think there is potential for VR in an educational context*

**Average score:** 4.6

70% of the users strongly agreed to this statement. Seeing that people were generally very positive to this statement, it is fair to assume that most users would somehow see it useful in some courses. Every user interviewed said that they saw potential in the concept of the deep learning introduction application when more resources are put into development. Since the statement was given after the users tested the application, this could imply that they also saw potential in using VR for AI courses specifically. However, there is a need to figure out how the tool is best utilized and how it can be applied as course material.

*I feel that the application was exciting to use*

**Average score:** 4.2

The responses to this statement were generally positive, which may mean that the users were satisfied with the problem-solving approach and felt that this was an interesting approach to teach a difficult topic. Seeing that the responses generally were less positive than for the previous statement, may be related to the lengthy and repetitive tasks. One thing worthy to note for this statement is that the users were generally inexperienced VR players. The excitement of using VR for the first time could have had an impact on the results of this statement.

*I would prefer to use a VR application over traditional learning methods (books, videos)*

**Average score:** 3.4

The responses to this statement were in average neutral. Seeing that people were positive about using VR in an educational context but neutral to this statement probably implies that they would rather use the VR application as a supplement instead of replacing traditional methods. This will further be looked into in Phase 2. One user strongly disagreed with this statement. This may suggest that using a VR application is not a suitable way of learning for all students.

***The application taught me something***

**Average score:** 4.1

Knowing that the users had varying experience with deep learning, the positive responses to this statement shows that the VR application may have a positive impact on learning outcome. In the weeks before the user test, the students had lectures about deep learning. Their prior knowledge of the topic could have made it easier to learn using the application. Another theory is that the students could have felt that the application was efficient for learning. These are just theories, but it would be interesting to see how the VR solution compares to traditional methods of learning about AI.

**Usability**

Generally, it seemed like most people picked up the fundamentals and started using the system efficiently in a meaningful way, considering the good SUS score of 75.5. Seeing that some of the responses to some statements were neutral to negative, may be a result of the design issues of the application, such as grabbed text disappearing in the user's hands. Usability details can be found in Appendix C.1.2. One thing to take from the usability of the application is to keep the interactions that worked well and focus on user-centered design and following standards for VR development.

***I experienced discomfort while playing***

**Average score:** 2.6

The level of experienced discomfort in VR should be as low as possible. Seeing that the responses to this statement averaged to 2.6 is too high for a VR application. As first time users of VR, it might be normal to experience a little discomfort, but this score is too high and should be minimized. Greater efforts need to be put into optimizing performance. Section 2.1.3 elaborates on how this is done.

## 6.2 Phase 2

This section will first discuss the participants of both types of evaluations conducted online. Then, the key findings will be discussed.

### 6.2.1 Evaluation Participants

Both types of evaluation conducted online had their strengths and weaknesses, which will be discussed in this section.

#### Online User Test Participants

9 out of 15 participants were from one of the subreddits or the IMTEL network. All of them were assumed to either own a VR headset or work on a VR related project. Knowing this, we can assume that their experience with VR was much higher than the average person in the target audience. Their attitude towards VR might also be more positive. Still, a person with more experience may have more insightful feedback than a user with lower VR experience, since they already know what works well from other applications. The fact that there were no personal interactions with most participants may have led to more objective results. Another thing to note is that some of the participants most likely tested the application on one of the tethered Oculus devices. Therefore, the discomfort score might not fully reflect the score of exclusively using the intended standalone device.

Considering the 6 participants from the author's student housing, their experience with VR was ranging from low to medium. One problem with this group was that the author knew them, and the personal relationship could have led to more positive results. Since all of them were computer science students and therefore had competence with user testing, their ability to remain objective could still have given reliable results.

#### Video Evaluation Respondents

Even though the participants were encouraged to watch a full play-through or test the application, there is no guarantee that they watched more than the 5-minute video. What did the participants base their responses on? They were encouraged to respond as well as they could, based on their assumptions. Most people do not possess an Oculus HMD. However, the respondents of the video questionnaire probably reflected the target audience better since it was also attempted to reach out to more students, researchers, and others within the field of AI. The same weaknesses discussed for online user tests count for this group. However, since they were less experienced with VR, they probably reflected the real target audience better.

The main goal of the video questionnaire was to get more feedback on general opinions about VR and the concept. It was taken into account that they did not have as much insight as those who tested the application.

## 6.2.2 Written feedback

12 of the 15 users submitted written feedback through the optional text question in the user test questionnaire and the comment section of the Reddit posts. This section discusses the key findings from the written feedback shown in Appendix C.2.3. The section will mainly focus on the written feedback that does not overlap with questionnaire statements. The next section will focus on more general opinions about VR and the application's concepts.

### Tasks

Multiple users mentioned that the escape room concept was good for learning and enjoyed solving puzzles to progress. Some users mentioned that they enjoyed the tasks for neurons and neural network notation. Seeing that users felt engaged, the puzzles seem to be one of the main elements that make VR beneficial. "Learning-by-doing" is often beneficial for understanding and remembering the curriculum. However, considering the notation tasks, some users ended up solving the tasks by trial-and-failure, due to a lack of understanding of backpropagation. Some users mentioned that they used the feedback sound to solve the task. For future work, the backpropagation learning materials should be improved, and the tasks should be designed to encourage users to properly solve them instead of using trial-and-failure. Compared to the Phase 1 application, it seemed like the introduction of more 3D elements improved the feeling of immersion, and justified the use of VR, even though some more improvement would be needed.

### Quiz system

Multiple users mentioned that they enjoyed the quiz system, even though some stated that the quizzes could have greater difficulty. Some users wrote that having to collect and win the cartridges to progress to the last room made the experience more engaging and rewarding. In contrast, one user mentioned that collecting cartridges felt unnecessary. We saw from the individual responses that the user who was negative about collecting cartridges was less positive to the concept in general. This brings back the importance of keeping a balance between learning and game elements, as discussed in section 6.1.2. Also, this might again imply that this way of learning is not suitable for every student. Some students prefer traditional methods since they can be more efficient, while others enjoy more visual and interactive ways of learning.

### Learning material

Considering the learning material, users had mixed responses. Most users were dissatisfied with the large number of text panels used for learning material. However, they wanted to see more of the interactive content, like the 3D-visualizations for gradient descent and neural networks.

- **Text panels:** The element that caused most dissatisfaction with the application was the large number of text panels used for learning materials. This feedback was expected. Section 4.3.4 discussed why the application ended up having such a large



amount of text panels, and what would be made with enough time available. Multiple users suggested minimizing the number of text panels and replacing them with other learning material types since reading was uncomfortable in VR and did not justify the use of VR.

- **Gradient Descent:** Most users mentioned that they liked the implementation of gradient descent. The participants from the student housing had an immediate positive response when they entered the room. Some users stated that this was the best utilization of VR technology. Seeing how positive users were to the gradient descent visualization, more efforts should be put into creating more content like this, to justify the use of VR in this context. The users also mentioned that the solution had more potential, and suggested letting the user place the ball and adjust step size.
- **Backpropagation:** Some users were confused by the theory behind backpropagation. Backpropagation tasks were somewhat designed to make the user solve them by a mix of applying the learning materials and intuition. However, since this led to confusion, more efforts should be put into conveying the topic. Implementing the planned animation for teaching backpropagation could help make the backpropagation learning materials better.

### 6.2.3 Questionnaires

This section will discuss the results of both questionnaires.

#### Concept

One of the more original results of this project is the users' satisfaction with the concept used for learning. The results of both questionnaires indicate that users were generally highly interested in the "educational escape room in VR" concept. Also, as covered in the written feedback and the video questionnaire, the users were positive about using dedicated rooms for each topic. Some users mentioned in the written feedback that having room layouts that look good, makes the experience more enjoyable. Multiple users stated that the puzzles, calculations, and quizzes based on the course-material made learning more engaging and that the separation of topics helped for having a natural progression. Section 2.3.3 discussed the use of educational escape rooms in education, but no studies were found where the concept had been exclusively applied in a VR environment. Seeing how interested users were in the concept, we believe that we have revealed a use-case for a learning model that could show great potential in education. This is especially relevant to courses that require a visual understanding of the curriculum, like STEM-courses.

#### 3D-Visualizations

One of the main advantages of using a VR application in this context is the use of 3D-visualizations for topics that are difficult to convey through other means. Users were very positive to the visualization of gradient descent and the use of visualizations used for neural network learning materials and tasks. The use of 3D-visualizations to convey difficult topics were also one of the main advantages from the findings of the literature

study, presented in chapter 2. The Phase 2 application showed an improvement of tasks compared to the Phase 1 application since the new tasks applied more 3D-models. In the future, the application should try to maximize the use of 3D-visualizations for conveying the curriculum.

### **Replacing Text Panels**

As mentioned in the previous section, multiple users wrote feedback about the high use of text panels for learning material. We realized that this feedback could better be covered through statements in the questionnaire. Therefore, for the video evaluation, we tried to get insight in what users thought about the current state of the learning material, and if they thought the application would have more potential if the text panels were replaced with more immersive types of learning materials. It already seemed like users were generally satisfied with the concept. Therefore, we assumed that people would be more interested in using the application if the text panels were replaced. This assumption was confirmed, seeing that users generally thought the use of text panels was too high and thought the application would have more potential if the learning materials were replaced. Since the lower performance in the last parts of the application somewhat worsened the reading experience, the text panels could have more potential if they are better designed for comfort, but the number of text panels used should be minimized. Formulas and notation would not be suitable for replacement, but replacing longer explanatory texts would increase immersion and engagement. Also, more topics from the AI curriculum could be conveyed through 3D-visualizations, audio, and possibly videos. For cost functions, room size animations of neural networks could display how values are calculated and transported through the network until the point a cost function is calculated. The same principles count for backpropagation. Some of the learning materials for gradient descent could be replaced with more interactive tasks of placing the ball to understand the algorithm step-by-step, instead of having to go through a sequential path of text panels before studying the visualization. Through the rooms, audio voice-overs could play automatically when entering certain parts of the rooms, or by adding buttons where the user can start the audio.

### **Applying the application in a course**

After Phase 1, the author had an assumption that a VR application would not be a suitable replacement of traditional learning methods, but could instead have potential as a supplementary tool. The responses to both questionnaires supported this assumption, seeing that users were neutral to negative to using it as a replacement but generally positive to using the application as a supplementary tool. In addition, people generally thought the application would be a good way of giving an introduction to deep learning.

One of the students who responded to the video questionnaire wrote a more extensive response, where he compared the learning method with other types of learning methods (see Appendix C.2.4). One of his key points was that the application's strength lies in the use of practical tasks and calculations to learn the curriculum. However, he stated that the same tasks could work just as well by other means and that thoroughly learning

the curriculum would require large amounts of training. Looking at the responses to the statement that attempted to measure whether people thought the method of learning would work well on a 2D monitor, we see that we do not have insight into how the VR application would compare to other learning methods. However, seeing the power of doing tasks in the application and the visualization of complex topics, the application could still have the potential for students who prefer a more visual and interactive way of learning. From this, we can make two assumptions about how the VR application should be applied as a tool for learning in an AI course. The first assumption is that the application could be a valuable tool for giving students an introduction to the topic and then let them proceed with other learning methods. The second assumption is that the current state of the application could not replace the training required to understand the curriculum entirely. Therefore, the application could be a suitable supplement or replacement of lectures. However, it would not be a suitable replacement for other learning methods, such as assignments and hands-on projects.

## 6.2.4 Fulfillment of Requirements

This section will discuss the fulfillment of the requirements defined in section 4.2.

### Non-Functional Requirements

ID	Type	Discussion
NFR-1	Reusability	Though the application, it was generally built a good foundation for reusability. Prefabs were developed for cartridges and doors. Also, the room structures objects for level design, and other assets can be reused to create more content. The calculator can also be easily reused and modified by swapping the activation function. The notation tasks were somewhat reusable but needs further work to increase reusability.
NFR-2	Usability	Based on the feedback, it seemed like users were generally picked up how to use the application quickly and were satisfied with the tutorial's length and contents. The users mentioned some bugs and design issues in the written feedback that should be fixed. Also, some users requested that alternatives for locomotion should be implemented for more experienced users. The users were generally highly experienced with VR, so a full SUS test should be conducted on a group that better reflects the whole target audience. Seeing that multiple users experienced discomfort, further work should be put into optimizing the application.

NFR-3	Modifiability	A high focus was put into keeping the application modular and documented, so making changes to the current code base should not be too difficult. Unity's event system was used to keep the different objects of the application modular so that references can be set up in the Unity editor, instead of "hard-coding" this in the scripts. Also, by using VRTK as an SDK for interactions, it should be possible to add support for other VR headsets than Oculus without too much effort. However, to update SDKs like VRTK, more extensive work would be needed to update references in the Unity editor.
NFR-4	Extensibility	Extensibility was facilitated in the quiz system for adding new cartridges. The game menu was developed with room for adding new AI topics. The assets can easily be reused to create more content. Especially the choice of using Unity Snaps [59] for building room layouts, makes it easy for developers to extend the application's contents with new rooms easily.
NFR-5	Performance	Through the first parts of the application, the performance is generally good and near to 72Hz. However, multiple users experienced discomfort in the last parts of the application because of performance issues. The issues were caused by a high amount of grabbable objects with TextMeshPro. This shows one of the weaknesses of using a standalone VR headset and the importance of focusing on optimization.

**Table 6.1:** Fulfillment of non-functional requirements

### **Tutorial**

All the functional requirements for the tutorial (see Table 4.2) were implemented as planned. Based on the observations of participants from the student housing, it seemed like the tutorial covered the necessary interactions well. Also, as discussed under usability in the non-functional requirements, it seemed like the users thought the application was easy to use and satisfied with the tutorial's length.

Considering T-FR5 about learning how to interact with physical UIs, the users had problems understanding how to point and use the pinpad. From the observations, it seemed like the touch sensor on the index finger trigger caused this problem. Since the users rested their fingers on the trigger, the virtual hand's finger bent and could not be used for interaction. A future solution to this would be to either disable the touch sensor on the index finger trigger or to automatically make the hand point when being near a physical UI.

## Deep Learning Introduction

This section discusses whether the functional requirements for the deep learning introduction (see Table 4.3) were fulfilled or not.

ID	Fulfilled	Discussion
FR1	Yes	The topics were separated in rooms like you see in Figure 4.9. Since backpropagation is a big topic, it was split into multiple rooms.
FR2	Kind of	The application used a too high amount of text for learning materials, but also used some 3D-visualizations. For future work, the text should be replaced with more of the other learning material types.
FR3	Mostly	Users understood the order of learning materials for neurons, cost functions and backpropagation, so they could apply it in tasks. Some users were confused by the order of learning materials for gradient descent. The learning materials for backpropagation seemed to be placed in an intuitive order, but were lacked content.
FR4	Yes	The quiz system was implemented and described in section 4.3.9. The quiz system had a few design issues, but users were generally satisfied with the way it worked.
FR5	Yes	Users seemed to understand the perceptron task.
FR6	Yes	Users seemed to understand the sigmoid neuron task.
FR7	Yes	Multiple users stated that this visualization was the application's best utilization of the VR technology and saw more potential in adding possibilities of manipulating the visualization.
FR8	Yes	This task was implemented to let users place neurons. One user mentioned that this was a better approach for learning notation, compared to lecture slides.
FR9	No	An animation for backpropagation was not implemented due to a lack of time.
FR10	Yes	The task was implemented, but users found it somewhat confusing to understand how to do the task using the available learning materials.
FR11	Yes	The questionnaire could be opened in the Oculus Quest browser.
FR12	Yes	Using the quiz cartridges to open the final door was something that some users liked. One user felt that it was unnecessary.
FR13	No	Implementing an open-ended task to put everything together was thought to be too time consuming for a master thesis project and should be prioritized for future work.

**Table 6.2:** Fulfillment of deep learning introduction functional requirements

## 6.3 Research Outcome

Through this section, RQ1, RQ2, and RQ3 from section 1.3 will be discussed, as an attempt to answer the main research question below. Then, RQ4 will be discussed to see how the project's findings are relevant to other STEM courses.

*RQ: Can virtual reality be utilized as a tool for learning in artificial intelligence education?*

### ***RQ1: How can virtual reality be used in artificial intelligence education?***

The respondents of both questionnaires were generally very positive about the concept of splitting the curriculum into separate rooms and introducing escape room elements like puzzles to progress through rooms. The concept proves to give intuitive progress through the curriculum, which lets students focus on one thing at a time. Since the AI curriculum consists of topics that may require a visual understanding or can better be conveyed through visualizations, a VR application shows the potential to be a valuable tool for learning. Most users stated that they learned something from both of the applications evaluated in this project and that they felt the tasks and visualizations made learning more engaging. It is unknown how this affects the learning outcome. The learning method should be compared with other methods in the future, using a more pedagogical approach. This project focused mainly on measuring engagement. However, the results give indications that this way of learning could possibly have a positive effect on students who prefer a more interactive and visual way of learning.

One of the main advantages of using VR in this context is when interactive 3D-visualizations are used to convey topics that are difficult to experience by other means. Users were generally very satisfied with the visualization of gradient descent and neural networks and showed interest in adding more interactive 3D-visualizations to justify the use of VR. The users had one main element that they were not satisfied with: the high amount of text panels used for learning materials. People often experience discomfort from extensive reading in VR, which also makes them impatient. Using large amounts of text does not justify the use of VR. However, most questionnaire respondents thought the application would have more potential when the text panels are replaced. The curriculum should mainly be conveyed through audio, 3D-visualizations, and possibly videos. This does not imply that text should be fully replaced, but that text needs to be well-designed for comfort, and the amount should be kept to a minimum.

The amount of resources needed to design and develop a VR application is quite high. Therefore, it is crucial to have a thoroughly planned architecture and design before implementing a VR application. The non-functional requirements for this application should be addressed upon further development. Building a good foundation by using existing assets and SDKs for interactions and creating and reusing prefabs, allows developers and designers to expand with new contents and easily modify the application efficiently.

***RQ2: Can a virtual reality application be implemented to give an engaging introduction to deep learning?***

As discussed above, users were positive about using interactive 3D-visualizations and felt that the escape room concept gave engaging progress through the curriculum. Since the deep learning curriculum consists of multiple concepts that are challenging to convey by other means, VR can prove to become a valuable tool for visualizing the topic. In conclusion, it is possible to use VR to give an engaging introduction to deep learning. A final application would require the replacement of textual learning materials and further improvement of tasks and learning materials. Once again, this project did not explore the learning outcome of using a VR application, compared to other learning methods. However, the results gave positive indications that applying VR in AI is worthy of further research. It could also be useful to look into if the same concepts could be implemented using other technological solutions, such as on an interactive website, and compare this to the VR solution. Educational escape rooms often use an engaging narrative, based on movies, TV-series, games, or books through the experience to increase engagement. There was not enough time to write a narrative for the application in this project. However, it would be interesting to explore how and if a narrative could improve the experience. Some of the assets used for the Phase 2 application had a sci-fi vibe. Artificial intelligence is a popular topic in many movies and TV-series, which could make it interesting to apply a sci-fi narrative to the application.

There are also other topics within deep learning and AI, like convolutional neural networks (CNN), and 3D environments for reinforcement learning, that builds on topics that show the potential of being conveyed as 3D-visualizations in VR.

***RQ3: What do students think about using such an application as a supplement to traditional learning methods?***

The respondents from both evaluations stated that they thought a VR application could be a good supplement to traditional learning methods. One possible use case for such an application could be to use it as a tool for learning something new. The main focus should be on topics that are challenging to convey by other means and facilitate interactive "learning-by-doing" tasks and 3D-visualizations. Therefore, the application could prove to be a valuable tool for giving students an introduction to topics within AI and then let them proceed with traditional learning methods for understanding the curriculum entirely. However, the game elements put on top of the curriculum may feel unnecessary and inefficient for some students. Therefore, it is important to focus on having a fair balance between actual learning and gamification elements. Also, as we realized in Phase 1, the application should avoid having repetitive tasks, since the feeling of impatience can be stronger when the user is fully immersed in a virtual world. As course material, the tool should be made accessible for students who prefer a more interactive and visual way of learning.

Furthermore, using standalone HMD in education comes with some restrictions considering performance. Since users experienced discomfort in the later stages of the application, greater efforts need to be put into optimization. However, the application developed for

this project shows what is achievable during the time of a master thesis project by a single person who did not have much prior experience with VR development and deep learning. Therefore, standalone HMDs could have much potential in education when more resources are put into development. If the goal is to use VR in AI education, a tethered HMD would require dedicated rooms for using the application. By using a standalone HMD, the course staff can bring multiple HMDs almost anywhere, and let students play through the application.

***RQ4: Are the findings relevant for other STEM courses?***

Through this project, the concept of an educational escape room in VR was explored. The use of puzzles to progress through the topic and concept of splitting the curriculum's topics into separate rooms was met with excitement from the respondents of the questionnaires. As discussed in this chapter, one of the main advantages of using VR is to convey concepts that require a visual understanding. Therefore, the concept could also be highly suitable for other STEM courses, like physics and chemistry. Currently, there are VR applications that lets students play around in virtual labs [40] and view 3D models in VR as part of lectures [41], as discussed in section 2.3. It would be interesting to see if the concept used for this project can be adapted to teach other STEM courses and see how the virtual memory palace's exploratory factor affects the learning outcome in combination with puzzles that need to be solved for progression. VR has already proved to increase student motivation and performance in education, but VR's successful applications in education are something we have seen only in recent years. Therefore, new concepts like the one used for this project should be further explored to understand how VR can best be used in education.

We do not know how the educational escape room in VR compares to classroom escape rooms, but one advantage VR has is that it would require little effort to set up. Also, there are possibilities of expanding with loads of content without too much effort, if the application has a good foundation of reusable assets and prefabs. The current VR application does not facilitate collaboration in the same way regular escape rooms do. However, it could be possible to implement multiplayer environments, where multiple players find themselves in the same environments. Some successful VR games have used asymmetric collaboration, where one player is within the VR environment, and the others assist the player through other tools, such as a mobile phone or a monitor. One study from 2019 explored what positive advantages this type of collaboration has in education [74]. The concept could be integrated with the concept used in this project to facilitate collaboration.

## **6.4 Reflection and Limitations**

This section will discuss the author's reflections around the project and discuss limitations.

### **6.4.1 Steep Learning Curve**

Through this project, I have had a pretty steep learning curve. I had a little experience with game development from LibGDX [75] from a previous software architecture course, but no experience with Unity and VR development. Therefore, I went through an intensive



learning process. The documentation for VR development is quite limited. It could have been easier to learn the basics by using SteamVR, but since I wanted to develop for the Oculus Quest, I had to use less documented SDKs. As I discussed in section 3.3, the Oculus Unity Learn course proved to be very helpful for building a good foundation. I did not have much prior experience with deep learning either. I had taken a few introductory AI courses, but not for deep learning. Therefore, it was highly time-consuming to create learning materials that could convey the topic in a meaningful way, as I discussed in section 4.3.4. One advantage of not knowing the topic too well was that I then ended up being a perfect fit for the target audience, which could have been beneficial for the learning materials' contents, sequence, and structure. This is particularly useful for future work when the text panels are going to be replaced.

Considering my prior experience with VR and AI, I am very satisfied with what I achieved through the project. Working with a maturing technology, where standards are not yet set, and the documentation is lacking is complicated. However, it has been a valuable lesson that has prepared me for my future as a software developer. My experiences from the project have also taught me what I would do differently if I had to start over. With more prior experience with VR development, I would have had enough time to design and implement an even better solution.

## **6.4.2 Resource-Intensive Development**

Before I gained the experience, it was harder to know what is possible for a single person to develop for VR. Therefore, I spent much of the time just playing around with Unity and the other tools before figuring out how I could efficiently develop for VR. The amount of work needed to develop something new for VR is quite high. In most cases, it would require a dedicated team of content creators, designers, and developers to create something that is well-functional and pleasing to look at. Objects in the virtual world need to be modeled, animated, scripted, made into prefabs, textures must be made, the audio needs to be added, lights must be added, and everything needs to be optimized. Through development, I had to narrow down my scope and focus on what was essential for developing a functional prototype. The decision to use only pre-existing assets, utilizing SDKs for interactions, and creating highly reusable prefabs gives room for one person to create loads of content.

If I had to start over, I would try to cooperate with designers and content creators so that I could focus more on the software development part of the project to develop better tasks, visualizations, other interactions and focus more on optimization. I wanted this to be my main focus through the project, but I still had to put in large amounts of effort in finding free assets, animating them, and creating learning materials. It was also challenging to come up with new ideas and designing meaningful tasks and learning materials since I had to think in a different way to design for VR. Therefore, I would have benefited from cooperating with others. However, I still feel that my dedication to the project has led to some interesting results considering how VR can be used to teach AI, and potentially other STEM-courses.

### 6.4.3 Scope and Lessons Learned

I feel like I have learned a lesson in the scientific process as well. Finding the relevant literature for an unexplored topic was difficult at first, but as I gained experience, I found more efficient ways of conducting the work. Reaching out to users for evaluation during a global pandemic is challenging and was somewhat a setback for the project. This was discussed through section 3.4.2. I think my idea of reaching out on Reddit led to some interesting results, and I am impressed seeing how random people in online communities are willing to help. Even though the video evaluation had its weaknesses, it also led to some interesting results, and it proved to be an efficient way of gathering feedback. In retrospect, I see that the questionnaires I distributed could have been further improved. The questionnaire used for the video evaluation, two months after the online user tests, was drastically improved in comparison. The questionnaire could be further improved by balancing the amount of negative and positive statements more. The scientific work conducted through this project has been a valuable experience that has taught me to work in a highly independent and structured way.

The amount of curriculum I attempted to convey throughout the application was quite high. When I realized that much effort would be needed to convey backpropagation, I considered scoping down the project to focus more on improving what was already developed. However, by doing so, I thought the end-user would feel the application would be too narrow to give an introduction to deep learning. Therefore, I realized that it is important to make the user test participants aware that the application is a prototype, rather than expecting a final product. Doing so can generate feedback that is highly valuable for the people continuing to work on the project. I realized during the online user tests that some users had high expectations for the application. Most users had a high focus on the number of text panels in the application, which obviously was valuable feedback. However, since this feedback was expected, I realized that it would better be covered through statements in the questionnaire. The video questionnaire covered this through two statements about what they thought about the current amount of text and what they would think about replacing text with more immersive content. I discussed the first questionnaire with my supervisor, but I could have benefited from discussing it with others in pedagogical studies or people with VR development experience.

Furthermore, when I started with the project, I had problems seeing how VR could be a useful tool for conveying the topic. My skepticism changed through the project as I saw the potential for applying 3D-visualization and tested state-of-the-art VR content. Also, I had not yet personally experienced VR being applied as a tool for learning in higher education in a meaningful way. I also thought the respondents of the video questionnaire would be less positive to the context of applying VR, but they were more positive than I expected. Therefore, after seeing what was achievable through this project, I genuinely believe that the concept of an "educational escape room in VR" and splitting topics into separate rooms can become a great learning methodology. Also, I believe that standalone VR is the way to go for applying VR in education. Tethered HMDs would require dedicated rooms and a cumbersome set up. However, after seeing how little effort was required for setting up Oculus Quests for multiple users in Phase 1, I believe that standalone VR is the best way to apply VR in a course.

# Conclusion and Future Work

## 7.1 Conclusion

This thesis explored how VR can be applied in AI education, with the hope of revealing a new engaging way of learning to fulfill the need for AI competence. The project consisted of two phases. In Phase 1, another application for teaching deep learning was evaluated, and we revealed that the application had potential. A new concept was defined for Phase 2, and a new application was developed, which then was evaluated. The new application applied educational escape room elements, to let users engagingly progress through rooms by solving puzzles, calculations, and quizzes based on the course-material. The participants of the user tests showed great interest in the hands-on activities. Also, the curriculum's topics were split into separate rooms to give the user intuitive progress through the curriculum, which multiple participants thought was helpful. The results indicated that the concept could teach deep learning well since the curriculum consists of multiple topics that show potential for 3D-visualizations. Topics such as gradient descent and neural networks can be implemented as 3D-visualizations. The use of interactive 3D-visualizations and "learning-by-doing" tasks for a more hands-on learning experience seemed to be the main elements that make VR useful in the context of AI. The concept could also potentially prove beneficial in other courses that require a visual understanding, such as STEM-courses. A VR application can give students a new level of immersion in the curriculum, and a more hands-on experience, compared to other learning methods. Also, the Phase 1 evaluation showed that interactive content in the form of grabbable learning material was useful for multiple users since users felt encouraged to bring them along and structure them in any way they liked. The author believes that this thesis has uncovered a concept that shows great potential in education, which is worthy of future research.

One possible use case for the application is to supplement lectures, where the application is used to introduce new topics, before letting students proceed with traditional learning methods. Since some students may feel that using such an application is unnecessary or

inefficient, it should be made available for students who prefer a more visual and interactive way of learning. The prototype application made for this project shows what is possible to develop through the time of a master thesis project by a single person. There is reason to think that developing VR applications is too resource-intensive, compared to other mediums. However, with enough planning, the right choices of technologies, and a good foundation, it is still possible to create large amounts of content in a relatively short period of time.

The prototype application developed for this project was made for the Oculus Quest, which was released in 2019. It was the first room-scale and fully standalone VR headset to reach the consumer market. Therefore, this master thesis is one of the first research projects exploring the use of a room-scale and fully standalone VR device in an educational context. Since the device runs on hardware similar to 2017-2018 smartphones, it requires more optimization to make applications run well. Therefore, larger amounts of effort had to be put into optimization as the application's contents grew in size. However, this project shows that a fully functional and immersive educational application can be developed for standalone VR headsets by putting in the right amount of resources. Compared to a tethered VR headset, which would require a powerful PC, sensors, and cables, the Oculus Quest only requires the headset itself and a pair of controllers. This could be the future of VR in education since the course staff could bring multiple devices to the classroom and let many students use an educational VR application. Also, as VR equipment is becoming more affordable and comfortable, the technology's future keeps looking more promising. Who knows, maybe VR will become affordable enough one day for anyone to possess and do the learning activities from home?

## 7.2 Future Work

### Implement the final application

The application developed for Phase 2 had many positive aspects that were discussed above. However, the final application is far from complete. The list below contains some important elements that should be addressed upon further development.

- The text panels used in the application needs to be replaced with more immersive types of learning materials, such as audio, more 3D-visualizations, and possibly videos.
- The visualization of gradient descent can be further improved by adding interactivity, that lets the user place the ball and adjust step size.
- An open-ended task should be implemented for the last room of the application, where the user needs to put together everything he learned.
- Some users from the evaluation in Phase 1 enjoyed using the grabbable notes. This was not implemented for the Phase 2 application to get more time to focus on new concepts and due to performance issues. Simple grabbable notes should be added to the final application.

- It should be even easier to add new tasks to the application. More extendable and reusable solutions should be designed and implemented.
- Even though it might not be necessary for an educational escape room, it would be interesting to see if there is a good way to measure user performance in the application.
- The learning materials for backpropagation somewhat led to confusion and needs to be improved.
- The application should be optimized to achieve stable 72 FPS to reduce experienced discomfort.
- There are also smaller details that could improve usability. This is covered in Appendix section C.2.3.

### **Thoroughly evaluate the application on the intended target audience**

The prototype was evaluated, and some valuable feedback was gained. However, due to the ongoing global pandemic, the application was not tested on the intended target audience. Therefore, in the future, the application should be user-tested on a group that reflects the intended target audience better.

### **Compare with traditional learning methods**

This project tried to measure the engagement and figure out how VR can be used as a tool to give an introduction to deep learning. Although this project has led to some interesting results on how VR can be a valuable tool in AI education, it remains unknown how the method of learning compares to other methods. VR opens for new possibilities that are not achievable through traditional ways of learning. However, whether it is worth putting the extra effort into developing a VR application compared to using, for example, an interactive website is unknown. Some of the results of this project indicates that the method of learning can be experienced as inefficient for some students.

### **Apply the concept in other STEM-courses**

This project has explored a concept for learning that could show great potential in other courses that require a visual understanding of the curriculum. The possibility of being fully immersed in a virtual world where users can manipulate 3D-visualizations based on course-material has shown to be valuable in a variety of studies. It would be interesting to look into how an educational escape room in VR with topics split into separate rooms could be applied in courses like physics and chemistry.



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# Appendices



## HELMeTO 2020 workshop

This chapter contains the revised extended abstract and the final version of the draft proceeding for the HELMeTO 2020 workshop at the University of Bari Aldo Moro in Italy. HELMeTO 2020 was an "International Workshop on Higher Education Learning Methodologies and Technologies Online".

### **A.1 Revised Extended Abstract**

The extended abstract was accepted on July 12, 2020. The revised version was submitted on July 13, 2020 and can be found on the next page.

# Using Virtual Reality for Artificial Intelligence Education

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**Abstract.** This project explored how virtual reality (VR) can be used in artificial intelligence (AI) education. A prototype VR application was developed to give students an introduction to deep learning using the Oculus Quest. The application applied escape room elements as an attempt to let students learn the curriculum in an engaging way by doing 3D-puzzles, calculations, and quizzes based on the course-material. The topics were split into separate rooms to let students progress through the curriculum intuitively. 15 people tested the application and responded to a questionnaire. 26 people evaluated the application's concepts after watching a video. Based on the evaluation, we believe that using such a VR application in AI education can be a good supplementary tool to introduce students to new topics. The main advantage of using VR in this context is to use interactive 3D-visualizations that are challenging to experience by other means. The questionnaire's respondents were very positive to the concept, and it could potentially be beneficial in other types of STEM-education as well.

**Keywords:** Virtual Reality, Immersive Learning, Mobile Learning, Artificial Intelligence, Deep Learning, Educational Escape Room, Learning Technologies

## 1 Introduction

Universities are applying technological tools for teaching, such as video lectures, interactive projects, and other supportive tools. However, universities mainly apply traditional teaching methods, and new alternative methods are rarely introduced. Furthermore, the difficult times of the global pandemic in 2020 have shown that having good technological tools in education is more important than ever.

The need for competence in artificial intelligence (AI) has increased rapidly in the recent years. That is due to the discoveries of new successful applications of AI and advancements in hardware and cloud solutions. In January 2020, Norway released a national strategy to be at the forefront in AI education, research, and innovation [1]. With the large need for AI competence, universities worldwide need to focus on educating students on the topic. Companies also need to put their employees through lifelong learning programs. AI is currently being taught through traditional methods like lectures, assignments, and hands-on projects. Students can also learn about AI through interactive projects like Google's Machine Learning crash course [2].



Since the release of the consumer virtual reality (VR) headsets in 2016, VR has shown potential in multiple sectors, including education. VR has not yet had a mainstream breakthrough, but newer technological advancements make the technology more promising than ever. After the Oculus Quest released in May 2019, the fully standalone device proved to give a highly immersive experience, without the need of an expensive PC and cumbersome setup with cables and tracking sensors. The device shows potential in education since it can be brought anywhere and is easily set up for multiple students.

Studies have shown that the feeling of presence in VR may increase the users' ability to recall information, compared to using a monitor [3]. With the rise of educational escape rooms, and its successful use in programming education [4], this concept was thought to have potential in VR as well. The goal of this project has been to investigate how VR can be used as a tool for learning in AI education. As a topic within AI, we have tried to discover if VR can be used to give an engaging introduction to deep learning.

## 2 Method

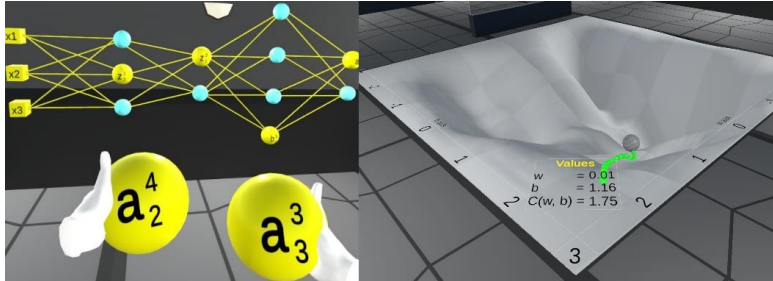
**Research Strategy.** The Design and Creation strategy [5, chap. 8] was used to implement a VR application for learning AI since there was no existing literature about using VR in AI education. The application was developed, following the waterfall development methodology [6].

**Technology.** The application was developed using the Unity game engine with the Oculus Integration SDK for hardware integration and the virtual reality toolkit (VRTK) for interactions. The application was developed for the standalone Oculus Quest headset for two reasons; to be able to conduct user tests on multiple users simultaneously and to create a more accessible tool for students compared to other VR headsets. One disadvantage of using the Oculus Quest is that the device runs on hardware similar to 2017-2018 smartphones. Therefore, applications developed for the device require higher optimization efforts compared to other VR headsets in order to maintain good performance in not too complex environments.

**Key concepts.** Before developing the application, another VR application had been developed for the overall project. It was user-tested, and we revealed that the project had potential. However, the learning material lacked structure, and many of the tasks did not justify the use of VR. The new application's concept was to split topics into separate rooms and introduce escape room elements, like puzzles, quizzes, and calculations that the user needs to complete to progress to the next room. The new application introduced more 3D-objects and visualizations for the tasks and learning material to justify the use of VR.

In one task, users need to place inputs on a neuron. With the correct output, the user can progress to the next room. In other tasks, users learn notation through puzzles where they place 3D objects, as shown in Fig. 1. A quiz environment was also im-

plemented, where users need to collect and win cartridges loaded with quizzes in order to complete the application.



**Fig. 1.** Image to the left shows a task where users learn neural network notation by correctly placing neurons. Image to the right shows a visualization of gradient descent. Unity’s terrain builder tool was used to mimic a cost function surface with two-dimensional inputs. The ball simulates gradient descent’s process of taking small steps in the direction of the negative gradient, to reach a minimum.

**Evaluation.** Two alternative ways of evaluating the VR application were planned and conducted due to the Covid-19 situation. The application was evaluated quantitatively through questionnaires that measured opinions related to various statements on a 1-5 scale. It was also evaluated qualitatively through written feedback.

*Online User Tests.* The application was distributed online in the IMTEL network [7] and Reddit VR communities. People with VR headsets participated from home. They were given a guide for installation on any Oculus device and submitted feedback upon completion. Some of the first author’s classmates also participated.

*Video Evaluation.* A 5-minute YouTube video explaining the application’s core concepts [8] was distributed online. Most of the participants from the online user tests were highly experienced with VR. Therefore, we attempted to reach out to AI research groups, AI students, and Reddit AI communities. People were requested to respond to a questionnaire about their opinions as well as they could, after watching the video. They were given a chance to watch a full play-through.

### 3 Results

**Application.** The resulting VR application is described in a 5-minute YouTube video [8]. In the associated video description, there is also a link to the full play-through and the tutorial. The application is considered a prototype.

**Evaluation.** The application was distributed in the groups mentioned in the previous section. 15 people responded to the online user test questionnaire, and 26 people responded to the video evaluation questionnaire. The results are not included here due to the page limitation.

Based on the feedback, we believe that the application's concept of splitting the curriculum's topics into separate rooms and encouraging students to solve puzzles to progress is an engaging and rewarding way of learning. The concept of "educational escape room in VR" could potentially be beneficial in STEM-education. Users were very positive about the use of 3D-visualizations for gradient descent and neural networks. They wanted to see more interactive 3D-visualizations, which is probably the main advantage of using VR in this context since it is challenging to experience this through other means. Compared to other teaching methods, the VR solution gives students a new level of immersion in the curriculum and a more hands-on experience.

The prototype had one main element that users were not satisfied with. The high amount of text panels caused discomfort, made users impatient, and did not justify the use of VR. Greater efforts should be put into replacing text panels with audio, 3D-visualizations, and possibly videos. This does not imply that text needs to be fully replaced, but that text panels need to be designed for comfort, and the amount should be kept to a minimum. One thing that worsened the reading experience was the lower performance in some parts of the application, where large amounts of content were being drawn. The application was optimized to some degree, but greater efforts must be put into optimization. The application shows what is possible to develop by a single person with little experience with VR development prior to the project. Therefore, we believe that standalone VR could be a great and more accessible tool for students when more resources are put into development.

The questionnaire respondents were positive about using the application as a supplementary tool for learning. We believe that a VR application like this could work well in the context of AI if the tool is used for learning something new. The focus should be on teaching what is challenging to convey through other means. One possible use case for the final application is for students to get an introduction in VR and then let them proceed with traditional learning methods to understand a topic entirely.

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## **A.2 Draft Proceeding**

The final version of the draft proceeding is shown on the next page and will be submitted to the HELMeTO 2020 workshop.

# Using Virtual Reality for Artificial Intelligence Education

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education, research, and innovation [17]. With the large need for AI competence, universities worldwide need to focus on educating students on the topic. Companies also need to put their employees through lifelong learning programs. AI is currently taught through traditional methods like lectures, assignments, and hands-on projects. Students can also learn about AI through interactive projects like Google’s Machine Learning crash course [7].

Since the release of the consumer virtual reality (VR) headsets in 2016, VR has shown potential in multiple sectors, including education. According to Gartner, VR was considered an emerging technology until 2017. In 2018, Gartner stated that the technology had reached a mature stage, due to the variety of successful use-cases [5]. Even though successful ways of using VR have been discovered, VR has not yet had a mainstream breakthrough. Newer technological advancements make the technology more promising than ever. In May 2019, the Oculus Quest was released. The device proved that a room-scale and fully standalone VR headset could provide a highly immersive experience, without the need of an expensive PC and a cumbersome setup with cables and tracking sensors. The device shows potential in education since it can be brought anywhere and is easily set up for multiple students.

Studies have shown that the feeling of presence in VR can increase the users’ ability to recall information, compared to using a monitor [11]. With the emergence of educational escape rooms, and its successful use in programming education [14], this concept was thought to have potential in VR as well. The goal of this project has been to investigate how VR can be used as a tool for learning in AI education. As a topic within AI, we have tried to discover if VR can be used to give an engaging introduction to deep learning and to see what students think about using such an application.

## 2 Background and Related Work

Through the literature study, we did not find any VR applications used in AI education and little research about using VR in computer science. To understand how an application could best be applied in an AI course, we studied VR applications used in STEM-courses to understand what makes these applications beneficial for learning. A study from 2016, defined some main aspects of what makes VR beneficial in education [15]. Their key points were that VR enhances the learning experience through studying 3D models, which further increases their motivation and engagement. In VR, they can interact, manipulate, and get immediate feedback, which can improve the learning outcome and experience. The new level of presence caused by being fully immersed in a virtual world that tracks the user’s movement and gives physical feedback through haptics shows the potential of creating experiences that would otherwise be impossible.

Game-based learning and gamification of education have also shown positive results for increasing engagement, motivation, performance, and learning outcome [10, 21, 8]. Effective educational games take advantage of the user’s ability to interact with the game to solve problems and reach goals. They also let the

student control the learning experience, make the learning experience challenging and rewarding, and stimulates the user through the audiovisual works [20].

Few projects have explored the use of VR in computer science topics. Some of the previous projects at the Norwegian University of Science and Technology explored the use of VR in algorithms and data structures [13]. The project results showed positive indications that students were interested in solving tasks in a "learning-by-doing" setting to get a hands-on experience, where they were immediately scored based on performance. The thesis concluded that one of the main advantages of the application was to give experiences that are otherwise hard to recreate. The tool showed the potential of being used as a supplementary tool. Since few projects have explored the use of VR in computer science topics, it is unknown how applying VR in this context affects learning outcome and performance. However, other projects where VR has been applied in STEM-courses has had a positive impact on learning. Examples of applications are the LabsterVR application [12], where students can learn topics from various subjects within biology, ecology, and physiology. In the application, they can do experiments that could otherwise be expensive or dangerous to conduct. VR is also currently being applied in various courses as a supplementary experience of the current subject being taught. By using ClassVR [2], teachers hand out teaching plans, and students use immersive experiences within a simple VR headset as part of the lesson.

Educational escape rooms are currently an emerging field. Students solve puzzles, riddles, and other activities to progress through one or more rooms. The activities often facilitate collaboration through class-room activities, but single-player escape room games have become widely popular among VR enthusiasts [3]. An educational escape room was applied in a web programming course successfully [14]. The learning activity has also been applied successfully in other fields, like pharmacy [4]. No studies were found where the educational escape room concept was exclusively applied within VR. However, the concept was thought to have much potential in VR by combining it with the elements that make other educational VR games useful. In the programming course study [14], they stated that the physical puzzles had a very positive impact on the experience, but that they could not be recreated for the digital tools. However, VR shows the potential for recreating almost anything from the real world, which we thought could prove beneficial in this context.

## 3 Methods and Implementation

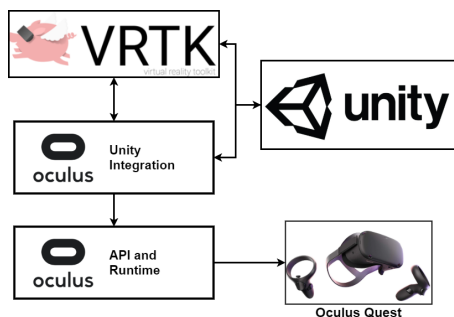
### 3.1 Research Methodology

The project followed the Design and Creation strategy [18, chap. 8] to implement the VR application for giving an introduction to deep learning. The research strategy was considered suitable since there was no existing literature about using VR in AI education. The application was developed, following the steps of defining requirements, design, implementation, and testing from the waterfall development methodology [6]. Git was used for version control, with a simple

workflow, to make sure that the project could be rolled back to a stable version in case something went wrong. The project is available in a public repository on Github [22].

### 3.2 Technology

Fig. 1 shows a simple representation of how the chosen technologies described below were related.



**Fig. 1.** This figure is a simple representation of the chosen architecture.

It was decided to develop the VR application for the Oculus Quest for two reasons; to be able to conduct user tests on multiple students simultaneously and to create a more accessible tool for students, compared to other VR headsets. The Oculus Quest is the first fully standalone room-scale device to reach the consumer market. It requires little effort to set up since there is no need for a powerful PC, cables, and external sensors. However, the device’s hardware is similar to 2017-2018 smartphones. Because of this, applications developed for the device requires higher optimization efforts, compared to other VR headsets to maintain good performance in not too complex environments.

Unity [24] was used as a game engine since it is easier to learn and use for independent developers and smaller teams, compared to alternatives such as Unreal Engine. The Oculus Integration SDK [25] was used for hardware integration, and the Virtual Reality Toolkit (VRTK) [28] was used for setting up interactions and locomotion. The fundamentals of the application were set up with inspiration from the Unity Learn course by Oculus [26]. It was decided only to use free assets found on the internet, to focus on developing a functional prototype. Prefabs were implemented for various objects, to effortlessly reuse them for activities, learning material, and other events triggered through the application. One thing that had a significant impact on the development efficiency was the use of Unity Snaps [27]. Unity Snaps consists of a variety of resources for efficiently creating real-size room structures.



### 3.3 Concept

Before developing the application, another VR application had been developed for the project. It was user-tested, and we revealed that the project had potential. However, many of the activities and the presentation of learning material did not justify the use of VR. Also, the learning material lacked structure. A new concept was defined based on the evaluation results and the literature study.

The new concept was to introduce educational escape room elements, like puzzles, calculations, and quizzes based on the course material. The different topics within deep learning were split into separate rooms to give the user intuitive progress through the curriculum. The idea was to split the curriculum into the topics; neurons, cost functions, gradient descent, and backpropagation, and further split these topics into smaller rooms when needed. The idea of splitting topics into rooms was inspired by the learning technique, virtual memory palace, which has been used since the ancient Greek/Roman times. Throughout the application, users progress through rooms by solving puzzles or other activities. The puzzles should apply 3D-objects and interactive 3D-visualizations to immerse the student in the curriculum. The intended target audience was students in introductory AI and deep learning courses, but a final application could also be made accessible to anyone interested in the topic. A thorough tutorial for teaching every type of interaction was needed since most people in the target audience were assumed to be new to VR.

### 3.4 Evaluation

Two alternative ways of evaluating the application were planned and conducted due to the Covid-19 situation. The application was evaluated quantitatively through questionnaires that measured opinions related to various statements on a 1-5 scale. It was also evaluated qualitatively through written feedback. All data collected was anonymous, and could not be used to identify a respondent.

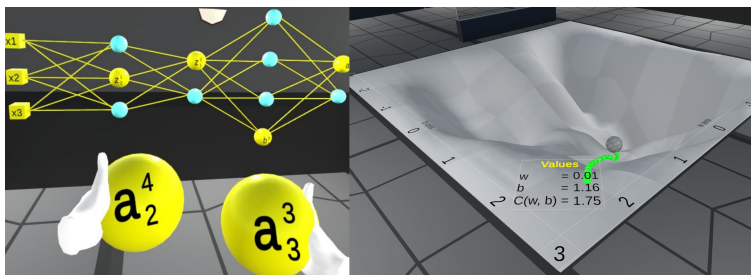
**Online User Tests.** The application was distributed online in the IMTEL network [9] and the Reddit VR communities `r/OculusQuest` and `r/oculus`. People with VR headsets participated from home. They were given a guide for installing the application on any Oculus device and enough context to participate. Upon completion of the application, they submitted feedback through a questionnaire. Some of the first author's classmates also participated.

**Video Evaluation.** A 5-minute YouTube video explaining the application's core concepts [23] was created and distributed online, along with a questionnaire. Most of the participants from the online user tests were highly experienced with VR. Therefore, it was attempted to reach out to AI research groups, AI students, and the Reddit AI communities `r/artificial` and `r/ArtificialIntelligence` and the groups involved in the online user tests. People were requested to respond to the questionnaire as well as they could, after watching the video. They were also given a chance to watch a full play-through for more insight.

## 4 Results

### 4.1 Prototype Application

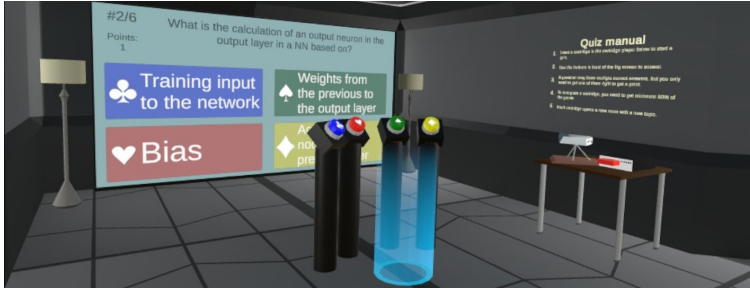
The resulting VR application is described in a 5-minute YouTube video [23]. In the associated video description, there is also a link to a full play-through of the application and the tutorial. More work is needed before applying the application in a course. Therefore, it is considered a prototype.



**Fig. 2.** Image to the left shows a task where users learn neural network notation by correctly placing neurons. Image to the right shows a visualization of gradient descent. Unity’s terrain builder tool was used to mimic a cost function surface with two-dimensional inputs. The ball simulates gradient descent’s process of taking small steps in the direction of the negative gradient, to reach a minimum.

**Learning Material.** Since the application was developed by a single person only, the main focus was on creating engaging activities and some 3D-visualizations. 3D-visualizations were developed for neural networks and gradient descent, as shown in Fig. 2. The application ended up having many text panels, which we knew were not optimal for VR. The plan was to apply more immersive types of learning material, such as audio, 3D-visualizations, and videos. However, an extensive amount of work was put into creating the contents of the text panels, so they show potential for being conveyed in more immersive ways. The curriculum’s topics were split into separate rooms, and within each room, the learning material was presented in a logical order. The learning material content was made with inspiration from Michael Nielsen’s book about deep learning and neural networks [16] and the 3Blue1Brown series on YouTube [1].

**Activities.** The application has three main types of activities. The first one is the puzzles, where the user needs to place 3D-cubes, and spheres for learning notation and building neural networks. An example is shown in Fig. 2. The second type of activity is calculations, where the user needs to calculate a neuron’s



**Fig. 3.** This figure illustrates the application’s quiz system area, where users can bring cartridges loaded with quizzes. The unfinished red cartridge has been inserted in the cartridge player on the right side of the image. The quizzes appear on the big screen, and the user can respond to it using the physical buttons in front of it. When every cartridge in the application is won, the user can collect them to complete the application.

output. This is partly done using mental arithmetic, but since one part of the calculation is too complex for mental arithmetic, the student can use a calculator. The final type of activities is quizzes. The user finds cartridges loaded with quizzes after learning each topic. They are then brought to the quiz system, shown in Fig. 3. The user completes the application by winning each of the quizzes and placing the cartridges in a bookshelf.

## 4.2 Evaluation

The application was distributed in the places mentioned in section 3.4. 15 people responded to the online user test questionnaire. The respondents were either current or previous computer science students. Their experience in terms of AI was varying. Most of them were highly experienced with VR. 9 of the users were from the groups reached out to online, and 6 were classmates with the first author.

26 people responded to the video evaluation questionnaire. 88% were previous or current computer science students. 62% of them were current students, while the rest were researchers, lecturers, or employed. Their experience with VR was ranging evenly from low to high. Their experience with AI and deep learning was also somewhat varying, but most of them had a higher experience.

**Questionnaires.** The most interesting results from the questionnaires have been visualized as Diverging Stacked Bar charts [19]. Fig. 4 shows the responses to the online user test questionnaire. Fig. 5 shows the responses to the video evaluation questionnaire. The vertical axis shows the various statements, while the horizontal axis represents the total amount of responses on both the agree and disagree side of the scale. The numbers on a bar represent the number of

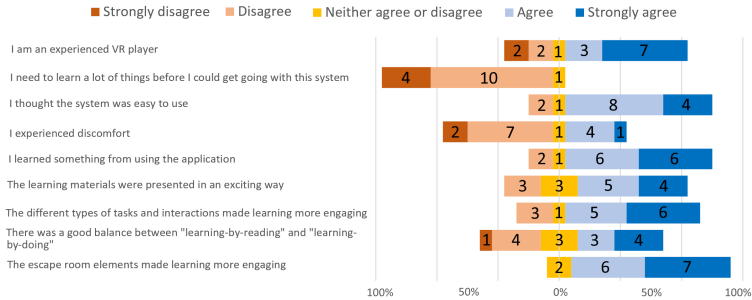


Fig. 4. Responses to the online user test questionnaire.

people with that response. A positive or negative response can be on either side of the scale, depending on the statement.

**Written feedback.** 12 respondents to the online user test questionnaire submitted written feedback. 8 submitted written feedback to the video evaluation questionnaire. Through their feedback, there were some key elements addressed. Most of the feedback covered below was submitted by the people who tested the application.

- **Concept.** Multiple respondents had positive feedback considering the application's concept. Some stated that dedicated rooms for each topic helped progress, and the room layouts looked good but should be more easily distinguishable. Also, the users enjoyed escape room elements like doing puzzles to progress.
- **3D-visualizations.** The respondents stated that they thought visualizations of gradient descent and neural networks were helpful. Some also stated that this was the best utilization of the technology. The users were interested in seeing more interactive 3D-visualizations.
- **Too much text.** Most respondents stated that the amount of text used for learning material was too high. They suggested replacing the text panels with more immersive types of learning material, such as audio, 3D-visualizations, and possibly videos.
- **Activities.** Multiple users stated that they thought the activities would be useful for learning. However, for backpropagation, some users were confused and ended up solving tasks by trial-and-failure since the learning material was somewhat lacking or confusing. Multiple users also enjoyed the quiz system solution and stated that collecting cartridges made the experience more engaging and rewarding. One user stated that collecting cartridges felt unnecessary. One user compared the activity for learning neural network notation to a lecture and felt that the hands-on experience made learning easier.

- **Applying the application in a course.** One of the respondents of the video evaluation questionnaire compared the method of learning with traditional methods. His key point was that the application’s strengths were through the use of practical tasks and calculations for learning the curriculum. However, compared to traditional methods, he considered the application inefficient for entirely understanding a topic since this would require mass-training.

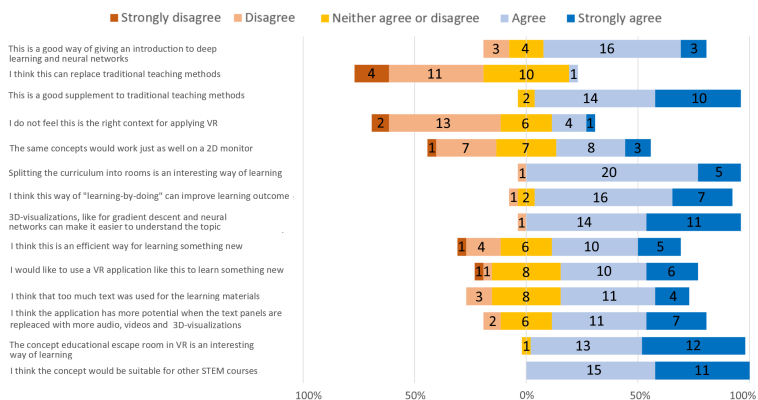


Fig. 5. Responses to the video evaluation questionnaire.

## 5 Discussion and Limitations

### 5.1 Research Outcome

The present study explored what students, researchers, employees, and others related to AI and VR thought about the application. The questionnaires mainly measured engagement, opinions about the concept, usability, how students would like to use the application, and attempted to get an indication of whether the participants felt that they learned something or not. The results show that the respondents of both questionnaires were generally highly interested in the application’s concept. The Background and Related Work section mentioned the successful usage of classroom escape rooms in a variety of contexts, but no previous studies had explored the exclusive use of educational escape rooms in VR. This project shows that physical puzzles can indeed be ported to VR experiences, and be received with interest from users. The current escape room games for VR have reached high popularity, and with the participants’ interest in the

concept, it can potentially prove beneficial in education in general. One of the main advantages of applying VR in this context is through the use of interactive 3D-visualizations, that are otherwise hard to replicate. Therefore, the use of separate rooms to convey complex topics through an escape room experience can potentially prove to be beneficial in other courses that require a visual understanding, such as STEM-courses.

The activities used throughout the application was also met with interest. The application developed for the project showed an improvement of the activities compared to the first application we evaluated since the activities were mapped to 3D-objects in the virtual world. The users seemed to enjoy the task of getting the right output on a neuron, doing calculations, and quizzes. The notation activities seemed to be useful for some users. However, since others ended up solving these tasks through trial-and-failure, either the activity type or the learning material needs to be improved or redesigned.

Considering how the application can be applied in a course, we see from the results that the users were positive about using it as a supplementary tool, but not using it as a replacement of traditional learning methods. The interactive 3D-visualizations and hands-on tasks were met with engagement and interest from the users. However, the large use of text panels for learning material did not justify the use of VR. Multiple users stated that they felt the amount of text was too high and suggested replacing it with more immersive types of learning material, such as audio, 3D-visualizations, and videos. This feedback was expected since there was not enough time to create such learning material, considering the project's scope. The results do not imply that text panels should be fully replaced, but that they should be designed for comfort, and the number of panels should be kept to a minimum. Some parts of the curriculum, such as formulas, are better conveyed through text and smaller pieces of information. However, their contents can be conveyed through a combination of text and other types of learning material. The reading experience was somewhat worsened throughout the application since the performance was not optimal in parts where large amounts of content were being drawn. More efforts need to be put into optimization to fulfill the performance requirements laid out by Oculus. Furthermore, the results indicate that using such an application in this context could work well if the students can use it to get an introduction to new topics, and then proceed with traditional learning methods. Therefore, the application might be a suitable replacement for some lectures but mainly a supplementary tool for the rest of the teaching methods.

## 5.2 Limitations

This study did neither compare the learning method to other learning methods nor attempt to measure learning outcomes. For future work, this would be required to determine if using VR in this context is useful compared to other learning methods. The study shows some positive indications of what can make the tool useful, but developing for VR is more resource-intensive than developing for-instance an interactive website. Even though VR opens for new possibilities

for conveying the curriculum, the methods should be compared. However, VR applications can be developed efficiently with the right set of tools, assets, reusable contents, and good design and architecture.

The VR application was designed and developed by a single person with a software-engineering background. It would have been beneficial to develop the application using a dedicated team of designers, software developers, and more pedagogical content-creators. However, the application shows what is possible to develop in a shorter period, by a single person with little previous competence with VR development.

The questionnaires were somewhat biased towards positive feedback. The questionnaire used for the video evaluation was drastically improved compared to the one used for the online user tests. However, future questionnaires need to be better designed to balance positive and negative feedback.

Due to the difficult times of the global pandemic of 2020, the application could not be tested on the intended target audience. The initial plan was to evaluate the application using students from an introductory deep learning course in a laboratory. This would be done in groups using six Oculus Quests. When we evaluated the other application developed for the project, we used this method and conducted interviews and observations. Since this was not possible when Covid-19 broke out, we chose the method we thought was the best alternative. However, the people who tested the application during the online user tests were generally highly experienced with VR, even though some of them had a lower experience. Therefore, the participants could have been more positive about using VR than the average person in the target audience. The respondents of the video evaluation questionnaire reflected the target audience better. However, they did not have the same insight since there was no guarantee that they watched more than the 5-minute concept video. For future work, the application should be user-tested by people that better reflect the target audience.

## 6 Conclusions and Future Work

Based on the feedback gained, we believe that the application's concept of splitting the curriculum's topics into separate rooms and encouraging students to solve hands-on puzzles to progress is an engaging and rewarding way of learning. The concept of an "educational escape room in VR" could potentially be beneficial in other types of STEM-education as well. There are two main advantages of using VR in the context of AI. The first one is to apply interactive 3D-visualizations based on the curriculum's concepts that are otherwise difficult or impossible to convey. The second advantage is through "learning-by-doing" activities that the students need to solve to progress. Compared to other teaching methods, the VR solution gives students a new level of immersion in the curriculum and a more hands-on experience. From the results, we saw that the participants felt that they learned something. The VR solution should be compared with other methods. However, we believe that we have uncovered a

teaching methodology that can be beneficial in courses that require a visual understanding of the curriculum.

We believe that a VR application like this could work well in the context of AI if the tool is used for learning something new. The focus should be on teaching what is challenging to convey through other means. One possible use case for the final application is for students to get an introduction in VR and then let them proceed with traditional learning methods to understand a topic entirely. The application shows what is possible to develop by a single person with little experience with VR development prior to the project. However, the application suffered from some unresolved performance issues. Therefore, we believe that standalone VR could be a great and more accessible tool for students when more resources are put into optimization and development. A tethered VR headset would require dedicated rooms for using a VR application, while multiple standalone VR headsets can be brought anywhere by the course staff. Companies who are putting their employees through lifelong learning programs can also apply VR applications with ease. Since some courses require prior knowledge in deep learning, the final application can also get students who lack this knowledge up to pace with the other students.

For future work, more efforts need to be put into improving the current application and designing new activities, learning material, and interactions. Before applying the final application in a course, greater efforts would be needed for replacing text panels, adding more interactive 3D-visualizations, improving and adding more activities, optimizing the application, and improving learning material contents. Furthermore, the application should be user-tested on a group that better reflects the intended target audience. Also, the VR application should be compared to alternative technological and traditional learning methods to measure the learning outcome and effectiveness of using VR.

Seeing how positive users were to the concept of an educational escape room in VR, some interesting future work would be to see how the VR application's concept can be applied in other STEM-courses, such as physics or chemistry.

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# Appendix B

## VR headsets

The report mainly covered the standalone devices in section 2.2 since it was decided to develop for a standalone device. An extensive work was conducted to get insight in what kind of HMD would be most suitable. Therefore, the other HMDs from the main stakeholders are covered here.

### Oculus - Tethered devices

Oculus VR manufactures some of the most popular HMDs. *Oculus Rift* (see Figure B.1a), their first virtual headset was released to the public in 2016. The device is now discontinued but is still fully supported. The device was initially used with an Xbox controller but started supporting 6DoF controllers after the release of the Oculus Touch controllers. *Oculus Rift S* (see Figure B.1b) is their latest tethered HMD, released May 2019.

Developing for the tethered Oculus devices gives a lot of freedom in choosing SDKs since they support "native" Oculus applications and also SteamVR applications, which gives a lot of freedom and makes the HMDs a good choice for new developers. Read more about SDKs in section 2.2.4.



(a) Oculus Rift with original Touch controllers and external sensors



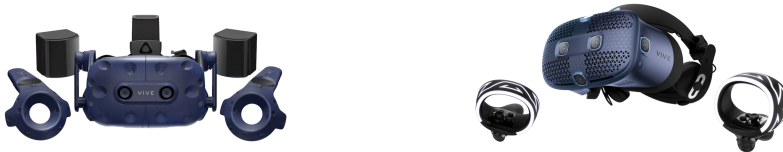
(b) Oculus Rift S with new Touch controllers

**Figure B.1:** Oculus tethered devices

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## HTC Vive - Tethered devices

HTC have released three tethered HMDs. They are also working on standalone HMDs, but these have not yet reached the consumer market. The first tethered HMD is the *HTC Vive*, which was officially released for consumers a short time after the Oculus Rift. The device was the first HMD available for consumers that were shipped with motion tracking controllers, the HTC Vive Controller. Two years later, in 2018, the *HTC Vive Pro* (see Figure B.2a) was released. It was both a design improvement of the HTC Vive, but it also came with better specifications. Both devices use the HTC Vive controllers, which has a more "chunky" look than the Oculus Touch controllers. The controllers give better tracking than the Oculus Touch controllers, but the Oculus Touch controllers have a more natural placement in the user's hands.



(a) HTC Vive Pro with controllers and trackers    (b) HTC Vive Cosmos with the new controllers

**Figure B.2:** HTC Vive tethered devices

In October 2019, the *HTC Vive Cosmos* (see Figure B.2b) was released. It supports inside-out tracking by using six embedded cameras. After the launch of the HMD, some tracking problems were discovered. A new Elite version of the HMD was released in March 2020, supporting external sensors for more precise tracking. The device comes with new HTC Vive controllers, with a similar design to the Oculus Touch controllers. The device can also be used with the original controllers.

## Valve Index

In June 2019, Valve released a high-tier HMD with powerful specifications and innovative controllers, that are strapped to the hand, allowing the user to fully release grip while playing. The device's release was very limited in Norway and the device was quite expensive. With the goal of creating an highly immersive experience, the HMD was definitely worth some consideration.

# Evaluation

This chapter contains the questionnaires used for evaluation and some results that were not necessary to show in the main text.

## C.1 Phase 1

### C.1.1 SUS Schema Results

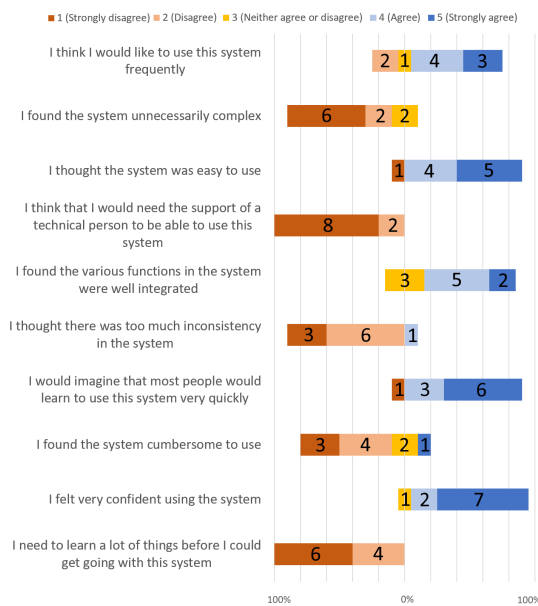


Figure C.1: Phase 1 user test results - SUS

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## C.1.2 Structured Interview Data

### *What do you think about this way of learning?*

- **Spatial memory:** Three users mentioned that they enjoyed learning in VR since it made them remember spatially where learning materials were placed. Some said that they thought using VR could be a more convenient way of learning and remembering the curriculum than browsing a book page by page. One user mentioned that spatial memory could be further facilitated by placing recognizable props in the environment.

*Reflection:* This feedback shows some of the advantages of using VR technology in an educational context. The feedback started the process of exploring literature about facilitating spatial memory for students. See the findings in section 2.3.4. From this application, the information placed on walls and grabbable information was something that could improve spatial memory.

- **Grabbable learning materials:** Multiple users stated that they liked being able to move notes of learning materials and organize them however they wanted. One interesting observation was seeing how differently people used grabbable learning materials. Some people used them very actively and structured them above the task table, while others barely touched them. The users who actively used the learning materials were more patient in trying to understand the curriculum before solving a task than others. Others used the materials on the walls more, and some were getting more impatient as time elapsed and started solving tasks by trial-and-failure. Some users said that they were overwhelmed when smaller notes had too much information.

*Reflection:* As some students enjoyed bringing the grabbable learning materials, this shows how the being able to manipulate objects increased engagement. However, it is important to keep the notes simple and instead place more comprehensive materials elsewhere.

- **VR has potential:** All users were positive about using VR for learning. Every user mentioned problems but still saw potential. One user stated that he liked to have an integrated system containing both learning resources and tasks. Two of the users mentioned that being inside a VR environment takes away eventual distractions since there is nothing else to do.

*Reflection:* The feedback shows that some students might be more focused while using VR.

- **Application in a course:** Through the interviews, it was discussed which part of a course an application like this could be useful. The students had varying opinions, but most of them said that they would like to use this type of application to get an introduction to a topic. Others said that it would be a great way to repeat a topic, but would not use it to get an introduction since the virtual world would be too distracting to focus. Some users said that they would not like to use the application for exam preparation.

*Reflection:* Seeing how varying opinions the students had, it would be interesting to look into what is the most efficient way of applying a VR application in computer

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science education. The feedback shows that there were interest in using such an application to get an introduction.

*Were there any tasks that you think worked better than others?*

- **Some engaging tasks:** Two of the users enjoyed throwing the ball in room 4. It added another level on top of what was being learned. The users also stated the importance of not using too much of this. In addition to this, one user mentioned that he liked the tasks where for building formulas and networks since this made the topic feel more like a "reality" to him. One user said that the building tasks worked well to get an understanding, but warned us that they could become boring in the long run. Also, one user felt that he learned most doing multiple-choice questions, but was a little bit afraid to make mistakes.

**Reflection:** This feedback shows the importance of having a fair balance between making abstractions and being concrete in tasks. "Gamification" should not be overdone.

- **Appealing room layout:** Through the user tests, more than half of the users stated that the tasks got repetitive, and only one or two users completed the whole application. One user said that he felt the first one or two rooms were more appealing to explore and that the exploratory element was what made him enjoy using the application. This feeling was reduced in the last two rooms.

**Reflection:** This shows the importance of the graphical work in VR applications. Having completely plain rooms might bore the user, so a greater effort should be put into creating an appealing room layout.

*Were there any tasks that did not work as well in VR?*

- **Repetitive tasks:** One of the biggest problems users had with the application, which also was observed was their impatience since tasks became very repetitive and lengthy. The main tasks that made users impatient were the ones for building neural networks, formulas, and matrices. One user mentioned that his patience and motivation is higher when having a pen and paper for the tasks that involved lengthy calculations. Some users stated that they felt less engaged when things got repetitive and stopped exploring for answers and rather solved tasks by trial and failure.

**Reflection:** From this feedback, we see that there is a need to vary in tasks used throughout the application to keep the user engaged. Also, since some of the tasks involved mindlessly filling out large matrices or formulas, it might be feasible to present this information to the user and test him in only parts of the information present.

- **Design problems:** Some of the grabbable objects with text disappeared behind the hand and led to confusion. Two users suggested utilizing the VR medium better by placing text on top of 3D objects. More of this below. It was also mentioned by every user tester that having to look down at a flat table for a longer time in VR led to neck strain. Multiple users mentioned that the table in the two last rooms was too large, with elements placed too near together.

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**Reflection:** Most of this will be discussed under the point "Utilize the VR technology" below.

- **Little difference from using a 2D screen:** Two users mentioned that most of the tasks would be just as well on a 2D screen.

**Reflection:** Since the tasks mainly were done on a screen in the middle of the room, they would be just as suitable for a 2D screen. There is a need to utilize the VR technology more by introducing 3D elements. This is further discussed in the next point.

*Do you have any suggestions for how the application could be improved? Ex. consider tasks, presentation of information, or gamification.*

- **Utilize the VR technology:** One user with more VR experience talked about the importance of not only mapping what you know works in 2D, but instead finding ways to present information and tasks with 3D-objects. The user mentioned that for example spheres could be used as neurons. Another user mentioned that there is a possibility of creating puzzles out of a neural network, that you need to complete to progress to a new room.

**Reflection:** 3D visualizations of for example gradient descent and neural networks could improve the users' engagement. By using more 3D objects, it could solve the problem of grabbing and not seeing the text objects that multiple users complained about.

- **Learning materials:** Users had feedback on how the learning materials could better be presented. One user talked about the lack of explanations and guidance in some tasks. He mentioned that some of the information provided felt more like lecture slides or somewhat random information, where he did not understand how it could be applied. Another user mentioned that he would feel more engaged if he had to deserve information by solving tasks.

**Reflection:** This feedback suggests that there might be a need of presenting information more sequentially and in different ways to improve the user's understanding. Also, it might be more engaging for the users if all information is not available when the user enters a room, to make it feel more rewarding.

- **Exploration:** The users had suggestions on how to make the application more engaging. Two users talked about their interest in having environments for exploring topics through interaction, trial, and failure, instead of only sequentially solving tasks on the same screen. One of them mentioned the possibility of visualizing the subject of gradient descent in a 3D terrain, where the user could place a ball himself to see what happens. Another person talked about the possibility of visualizing a neural network, where the user could manipulate weights, biases, layers, etc. to see what happens.

**Reflection:** Implementing these types of interactions in VR can be very time-consuming, but it still might be what users need to be truly motivated for using VR for learning and getting engaged in the topic.



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*We are looking for ways of making the application more engaging. What do you think about using elements from for example escape rooms on top of what already exists?*

- **Escape Room elements:** All users were interested in the possibility of getting codes from solving tasks, that allows you to unlock the next room, building keys out of puzzles and generally make the application feel more like a challenge. One user mentioned that he thought that some topics would do well being solved in an arbitrary order, but that others would need a sequential order of problem-solving.

**Reflection:** The question was created based on the assumption that bringing these ideas to life would be an interesting way to teach computer science, after the literature study (see section 2.3.3). The feedback confirmed this assumption.

*What did you think about the tutorial? Were there any parts of it you found challenging?*

- **Intuitive tutorial:** From observation and in conversation with the users, we got the impression that they quickly understood how to use the application. Some users already knew the basics of VR and played rapidly through the tutorial. Others were a little bit confused but still got through.
- **Affordance:** One user mentioned that the notes could more clearly indicate that they can be physically grabbed. We also observed and discussed the problems with the menu button, since more than half of the users pressed the menu button on the right controller, which led them to the Oculus menu. One user mentioned the possibility to show a model of both controllers, indicating that the left controller is the one to be pressed.

## C.2 Phase 2

### C.2.1 Online User Test Questionnaire

#### DL app feedback

Thank you so much for playing through the application. Your feedback is very valuable to me for being able to complete my master thesis.

The application was created by Sølve Bø Hunvik at the Norwegian University of Science and Technology during his master thesis project at the Department of Computer Science.

All data collected is anonymous. The data will be used for research purposes in the related master thesis report.

*Do you study or have studied computer science? \**

- Yes
- No

*Did you play through the whole application? \**

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- Yes

- No

***We need an overview of the users' experience with VR and AI/Deep Learning.  
How much do the following statements suit you? \****

	1 (Strongly disagree)	2 (Disagree)	3 (Neither agree or disagree)	4 (Agree)	5 (Strongly agree)
I have knowledge of and/or experience with AI/ Machine Learning/ Deep Learning.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I am an experienced VR player.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

***How much do you agree with each of the following statements about usability? \****

	1 (Strongly disagree)	2 (Disagree)	3 (Neither agree or disagree)	4 (Agree)	5 (Strongly agree)
I needed to learn a lot of things before I could get going with the application.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I thought the application was easy to use.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I experienced discomfort using the application (ex. motion sickness, headache, eye strain, dizziness).	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

***How much do you agree with each of the following statements about learning? \****

	1 (Strongly disagree)	2 (Disagree)	3 (Neither agree or disagree)	4 (Agree)	5 (Strongly agree)
I learned something from using the application.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
The learning materials were presented in an exciting way.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I consider this way of learning as a good supplement to traditional learning methods (such as lectures, videos, books)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I prefer this way of learning over traditional learning methods.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
The different types of tasks and interactions made learning more engaging.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
There was a good balance between "learning by reading" and "learning by doing".	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I think there is potential for using VR in an educational context.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
The application takes advantage of the VR technology in a meaningful way.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
The Escape Room elements of the application made learning more engaging.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

***Is there anything else you want to give feedback on or do you have suggestions for improvement? (optional)***

Long text answer

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## C.2.2 Video Evaluation Questionnaire

A VR application was developed as part of a master thesis project, to explore how virtual reality can be utilized as a tool for learning in artificial intelligence education. Please watch the video below and respond to the questionnaire as well as you can, based on your assumptions.

If you are interested in playing through the application as well, you can download it for Oculus Quest, Rift, or Rift S here: [link](#). Installation guides are provided for all devices.

The application was developed by Sølve Bø Hunvik at the Norwegian University of Science and Technology in the Department of Computer Science. Frank Lindseth was the thesis supervisor.

All data collected in the questionnaire is anonymous. The data will be used for research purposes in the related master thesis report.

### Watch the video

<https://youtu.be/Tv1N-dxAn4M>

### Experience with VR and AI and general opinions

Thank you for watching the video.

You should have had the chance to play through the application to get full insight, but please respond to the questionnaire as well as you can, based on your assumptions.

If you want more insight, you can watch a full playthrough here: <https://youtu.be/Mfcauc-pD8>. Use the timestamps in the video description to watch specific parts of the application.

Before giving your opinions about the application itself, we need an overview of your experience with VR and AI and your general opinions about VR.

***Did you also play through the application? \****

- Yes
- No

***Do you study or have studied computer science? \****

- Yes
- No

***Which of these describes you best? \****

- Student
- Employed
- Teacher/Lecturer
- Researcher

- None of the above, but curious about AI

***How much do you agree with the following statements? \****

	Strongly disagree	Disagree	Neither agree or disagree	Agree	Strongly agree
I have a lot of experience with VR.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I think VR has potential in education.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I think that standalone devices, such as the Oculus Quest has more potential as an educational tool, compared to other VR headsets.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I am skeptical about using VR in education.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I have a lot of experience/ knowledge of artificial intelligence.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I have much insight in the theory behind deep learning and neural networks.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I enjoy playig video games	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

## **Learning and engagement**

A full playthrough of the application takes approximately 30-90 minutes, depending on the user's experience with VR and deep learning. The tutorial takes approximately 5-10 minutes.

One thing that was not mentioned in the videos is that the perception of depth in VR makes it easier to see the depth of the cost function surface in the gradient descent visualization compared to on a monitor.

***Please respond to the questionnaire below as well as you can, based on your assumptions. \****

	Strongly disagree	Disagree	Neither agree or disagree	Agree	Strongly agree
This is a good way of giving an introduction to deep learning and neural networks.	<input checked="" type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I think the puzzles make learning more engaging.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I think this can replace traditional teaching methods.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
This is a good supplement to traditional teaching methods.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I do not feel this is the right context for applying VR.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
The same concepts would work just as well on a 2D monitor.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Splitting the curriculum into rooms is an interesting way of learning.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
The learning materials were presented in an exciting way.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I think this way of learning could motivate more students to specialize in artificial intelligence.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

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I think this way of "learning-by-doing" can improve learning outcome.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
3D-visualizations, like for gradient descent and neural networks can make it easier to understand the topic.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I think this is an efficient way for learning something new.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I would like to use a VR application like this to learn something new.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I think that too much text was used for the learning materials.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I think the application has much potential when the text panels are replaced with more audio, videos and 3D-visualizations.	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
The concept educational escape room in VR is an interesting way of learning	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
I think the concept would be suitable for other STEM courses (science, technology, engineering, mathematics)	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

***Do you have any other feedback?***

***Is there anything specific that you liked or did not like?***

***Do you have suggestions for improvement? (optional)***

Long text answer

### **C.2.3 Online User Test Structured Written Feedback Data**

12 people submitted written feedback in the online user test questionnaire. The data has been structured along with feedback from the comment sections on Reddit.

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## Learning

- **Topics in different rooms:** One user mentioned that having different rooms was helpful to prevent getting overwhelmed with information. Another user mentioned that he liked that theory was “fed to him in bits” when he got tested along the way. Another user mentioned that the separate rooms were good for progress.
- **Learning materials:**
  - **Gradient descent visualization:** Multiple users mentioned that they liked the gradient descent visualization. Every user from the student housing had an immediate positive response when they entered the room. Some users also mentioned the potential of adding interaction to the visualization, like being able to change step size, momentum, placing the ball, and changing the algorithm. These ideas were actually planned in section 4.12, but not implemented. Multiple users mentioned that they would like to see more similar visualizations through the application.
  - **3D visualization of neural networks:** One user mentioned that the use of 3D elements for learning materials and puzzles were nice. Another user mentioned that he would like more interactive content to learn the curriculum.
  - **Improve or replace text panels:** Multiple users mentioned that the amount of text used in the application was too high and should be replaced with more audio, videos, and visualizations. This feedback was expected (see section 4.3.4). Some users mentioned that the text caused discomfort and eye strain. One user mentioned that it was easier to read in the application than expected. Some users suggested improvements for using text in VR, like using curved panels, keeping text size consistent and adding teleport anchors to more easily stand at the optimal distance from the screen to read.
  - **Difficult to view images:** Some users mentioned that the images on the panels were difficult to view. As mentioned in section 4.3.4, there were some unresolved compression problems that reduced the image quality when standing too far from the panel.
  - **Order of learning materials:** In the gradient descent room, some users were confused by the order of the panels. One user mentioned that it was hard to read the panels that were overlapping in the gradient descent room, due to the panels’ transparency.
- **Interesting room layouts:** Some users mentioned that they liked that the rooms had an interesting layout with decorations. One user mentioned that adding paintings of things like neuronal networks and biological neurons could make the experience even more interesting. One user mentioned that the rooms could have been more easily distinguishable, to make it harder to get lost.
- **Need more explanation of backpropagation:** Some users mentioned that they did not fully understand backpropagation. The learning materials were somewhat lacking. Some of these tasks were built with the idea that the user should understand



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how the elements of the chain rule were related by intuition from the formulas, but some more explanation would be needed.

- **Context of using VR:** One user mentioned that he did not see the upside of using VR in this context and stated that concepts like interactions, keys, and escape room elements could somehow be implemented in a web-page as well. The same user also stated that implementation and visualization were good for such a difficult subject.
- **Provide use-cases:** Some users mentioned that the application should provide more examples of how the theory is used in practice in addition to learning the theory. One user recommended adding examples for how to determine how many layers and neurons to use practice.

## Tasks

- **Quiz system:** Multiple users mentioned that they enjoyed the quiz system. One user mentioned that there could be greater difficulty in the quizzes. One user mentioned that he felt that using the cartridges were unnecessary, while others mentioned that they liked having to place all cartridges to reach the final room; it felt like a reward.
- **Escape room elements:** Multiple users mentioned that the escape room concept was good for learning. Using gamification for tasks to progress made learning more engaging for multiple users. One user wrote that “mini-games” made the learning process easier, and mentioned that even though the escape room elements were not necessary for learning, they made the experience more engaging.
- **Notation tasks:** Some users were lost on the theory behind backpropagation when they got into the rooms for building formulas. When they got stuck, they used the feedback sounds from the tasks to solve the tasks by “trial and error” guess through their way through the rooms. One user mentioned that more explanations would be needed to understand the formulas. Another user mentioned that the task for building the chain rule was useful for understanding the concept. Compared to the application from Phase 1, one user mentioned that the use of 3D objects made it harder to give a wrong answer.
- **Neuron notation task:** One of the users wrote that he enjoyed the neural network notation task. Compared to lectures where he found this confusing, he mentioned that “learning-by-doing” was a better approach. One user mentioned that it was confusing that there were more open spaces than neurons in this task.
- **Final task for putting everything together:** One user mentioned that he did not know how to put together what he learned in the end and suggested having a final task for implementing a simple neural network for some use-case. Having a more open-ended task, in the end, was part of the concept of creating an educational escape room (see section 4.1), but was not implemented due to lack of time.
- **Use VR for practicing only:** One user suggested that users could instead learn the topic using traditional ways of learning, and then instead get tested using puzzles in VR.

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## Usability

- **Locomotion alternatives:** There was mixed feedback on the teleportation solution. This might be a result of having mainly users with high VR experience. However, one user requested having alternatives for locomotion, such as smooth locomotion, snap turns, etc. for advanced users. One user mentioned that the activation of teleportation was annoying when trying to test hands. In contrast, others mentioned that this was a good implementation since the pointer was easy to use and could be used to read the text.
- **Placing cartridges in bookshelf:** The bookshelf in the first version had many snap zones for placing cartridges. Some users did not find this intuitive. As a response to this, four light-blue objects indicating where to place the cartridges were added.
- **Improve performance:** Lower performance caused discomfort. This was most significant in the last rooms for learning backpropagation when reading text—the framerate drops. There were made some attempts to improve performance (see section 4.3.1.1), but the performance was still not at the recommended 72FPS.
- **Prevent users from cheating:** One user mentioned that he could look through the wall and teleport to the next room. Preventive measures for avoiding users from cheating should be implemented.
- **Tutorial:** Users were generally satisfied with the tutorial. The users from the student housing were probably the ones with the lowest VR experience. They were observed to understand how to use the application easily, even though they experienced some minor problems here and there. One user mentioned that the game flow of the tutorial was well designed. One thing that was observed with the users from the student housing was that they had trouble interacting with the physical UI, because of the touch on the trigger controllers, that held the index finger down. One of the users mentioned that this problem would be solved if the finger was instead automatically pointing when near a physical UI, instead of having to control this.
- **Quiz system:** One user wrote that the quiz system reminded him of Kahoot, which made it easier to understand how to use it. One user mentioned that it would be great to have more time to see the results of an answer and to get feedback on why an answer is wrong. Another user mentioned that it would be easier to use the quiz with a restart button than having to eject and insert it again.
- **Well-chosen colors:** One user mentioned that the colors chosen for the application were comfortable.
- **Physical buttons:** Some users experienced that the physical buttons were too sensitive and “glitchy” if they were not careful while clicking them. This some times made the buttons register multiple clicks.
- **Need more polish:** Some users mentioned that they thought the application worked well for learning but would be better with more polish since some users experienced minor bugs.

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- **Feedback:** Some users mentioned that the feedback sounds were useful.
  - **Physics:** One user mentioned that it was great that the objects did not have gravity since they did not get lost.

## C.2.4 Video Evaluation Unstructured Written Feedback Data

8 people submitted a written response to the video evaluation questionnaire.

1. I think the main benefit of a VR headset for teaching AI is in the ability to do 3D visualizations, so I think more focus should be on that. This is something that is not as easy to show on a blackboard. In addition to gradient descent, other topics that can benefit from 3D visualizations are convolutional neural networks and clustering methods, as well as 3D environments for reinforcement learning.
2. In my opinion the most important strength of this application is that it encourages the student to do practical tasks/calculations with the topic-material. The tasks may seem more interesting and fun this way than with pen and paper, which is positive. Nevertheless, I believe that if a student motivates himself to do the same amount of tasks on pen and paper it would have the same effect. Another strength is that the subject-material can be available within the room without presenting it upfront to the student. Then the student has to actively search for the necessary information in order to solve the tasks at hand. This is more engaging, and a more active form of learning than if the information was presented on a computer screen right besides the tasks. I still have my doubts about VR for education, as I believe the same learning effects can be achieved by doing tasks in a non-virtual environment. The tasks shown in the video seemed a lot like common learning examples given in the courses TDT4195 and TDT4265, and doing those tasks with pen and paper should in my opinion be just as good. Another point is that for me personally, learning in real life is a lot like learning deep networks, I need to do quite a number of different tasks before I understand the subject. I don't learn a concept fully from doing a single task. Both creating and solving a large number of tasks will take more time in a VR-environment than in real life.
3. I think just the fact that you are moving around while learning can improve the learning process (staying active, better bloodflow etc), thus suitable for any topic. Not necessary perhaps (?) to add more audio/video to gamify it more. After all, a student learning AI is interested in learning, so probably does not mind the reading. Sending this to colleagues in the department of education as well.
4. I tried out the pre-existing demo, and I must say that it has improved a lot. Especially, the improved coherence through a puzzle-like game, more '3D interaction' and generally improved visualization makes the experience a lot better. Great work!
5. Reading text on a computer screen is less fun than reading it in a traditional book. Even worse is a VR image, sorry.
6. The questions in this questionnaire are biasing the respondent towards positive feedback. I think the questionnaire has to be redesigned.

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7. Great work! I'm impressed!
  8. Good job! Looks interesting.

