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Abstract

This thesis sought to find what potential interactionless VR has in education. In order to explore this, perceived satisfaction, immersion and agency were investigated. A prototype of an interactionless VR application was created, and a user evaluation was conducted. The evaluation consisted of a pre- and post-questionnaire, interview and observations. It was found that interactionless VR seems beneficial to those who have little to no previous experience in VR. However, apart from this interactionless VR displayed no other aspects that would make it more beneficial than interactive VR in education.

Sammendrag

Denne oppgaven forsøkte å finne ut hvilket potensial interaksjonsløs VR har innen utdanning. For å utforske dette ble oppfattet tilfredshet, oppslukthet og autonomi undersøkt. En prototype av en interaksjonsløs VR-applikasjon ble opprettet, og en brukerevaluering ble utført. Evalueringen besto av et pre- og post-spørreskjema, intervju og observasjoner. Det ble funnet at interaksjonsløs VR virker gunstig for de som har liten eller ingen tidligere erfaring i VR. Men bortsett fra dette viser interaksjonsløs VR ingen andre aspekter som ville gjøre det mer gunstig enn interaktiv VR innen utdanning.

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Abbreviations

VR	=	Virtual reality
VE	=	Virtual environment
HMD	=	Head-mounted display
CAVE	=	Cave automatic virtual environment
FoV	=	Field of View
UX	=	User experience
E-learning	=	Multimedia learning using electronic educational technology

Chapter 1

Introduction

1.1 Project Background

Since the early 90's the uses for virtual reality (VR) in education have been the focus of researchers [7]. However, since then the field is has changed with cheaper and more easily accessible VR-devices. Gone are the days of the CAVE-system and its price tag of up to several hundred thousand euros [17], modern VR-devices can be acquired for as little as 400 euros. This makes the educational potential of VR increase immensely as these devices can now feasibly be acquired and used by far more educational institutions. A report made in 2017 projected that the global VR market would reach 48.5 billion USD in 2025 [4], a staggering number. With numbers as large as this, it is vital that the proper research is conducted beforehand.

Virtual reality excels at teaching subjects that require simulation and 3D models such as astronomy, architecture or medicine [15]. However, there are other fields where that either is not an option or not sufficient, computer science being one of them. Concepts such as recursion and iterative loops have one inherent problem that make them difficult to visualize in VR. That being there isn't just one way to implement these, there are multiple different implementation with different purposes. Unlike say a 3D model of a heart, where one well implemented solution could teach many of the intricacies of a heart, one could not truly learn recursion or iterative loops with just one implementation. Several examples should be provided to the student in order to give them an overview of how the specific implementation would affect the execution of the code.

Developing for VR is expensive [6, 31], and cost will scale with how complex the application is. If one were to implement several examples of iterative loops utilizing most of the features of virtual reality this could easily become cost-prohibitive. However if one were to cut down on some of these features it would be far more easily implemented, and as such the price would be lower. Virtual reality provides a range of features that have been shown to increase the learning benefit such as immersion [19] and interaction [15]. However, as far as the author can tell most of the application that has been tested to find data on interaction has been applications were the interaction has been removed. However, if one were to create an application specifically with no interaction in mind, how will this affect the perception of users?

In order to ascertain whether this is a viable path for VR I will be creating an application in VR that will be very light on interaction. To refer to this concept I have coined the term ”interactionless”. The concept refers to interacting with elements of the game, rather than all forms of interaction. This means that users will be able to control for instance when to start a demonstration in the application, but not be able to physically move objects, grab them, etc. While the application will not be entirely interaction-free, the user will be very limited in what actions they can take, and when. This approach in the application will be comparable to the traditional approach to teaching, where the information flows from the teacher, in this case the application, to the student.

1.2 Motivation

As there has been little research into an application that is created to be interactionless, this will be an exploratory research to find whether this is a solution that is worth pursuing further. Certain benefits to this approach can be thought of, as will be further discussed in this section, but does the positives outweigh the negatives? This is the crux of this thesis, what are the negatives of this approach, and how does it affect users.

As mentioned, development for VR is expensive, both in price and man-hours. Development of educational applications could potentially take several months to complete and cost hundreds of thousands or even millions of NOK. By reducing the number of features both development time and price will be reduced. Being able to cut costs and still provide an educational experience to users would be of immense help to organizations looking to create educational applications. In addition, the knowledge prerequisite for developing VR applications will be lower. This could lead to more developers being able to create applications, as well as them being able to start development earlier. This could lead to more applications hitting the market, both in topics that are usually featured in VR applications, such as medicine, as well as those topics that are less common to teach in VR, such as computer science.

To the authors knowledge very little research has been done on computer science in virtual reality. While I can only speculate as to the reason why so little research has been conducted I believe one of them is the difficulty of implementing a solution capable of teaching the topic. One of the problems as mentioned are the open-ended nature of several programming concepts. However, another problem is the abstract nature of computer science. Many of the concepts encountered in computer science have no real-life equivalents, and this makes it difficult to implement in an application that in many ways attempt to imitate the real world. As such the solution I propose will take an approach where the visualization is the focus, and not the user interacting with the system. However, computer science is not the only topic that could be featured in a solution similar to the one I propose. This means that the knowledge gained from the research would be applicable to the development of similar VR applications in other fields as well.

1.3 Problem Formulation

The proposed solution is light on interaction, which separates it from most other VR applications.

The main objective of this thesis will be to explore whether an interactionless VR application can be useful as an educational tool. The application will be very light on interaction in order to develop a better understanding of whether trimming this can under certain conditions lead to a net positive. In order to gauge whether the application was useful two factors will be looked at. Perceived satisfaction has been linked as one of the most critical factors to determine how successful an e-learning implementation has been [29]. The other factor will be the subjective user experience, and which aspects of the application affected it the most. In addition, to aid future research the approach taken to implement this application will be detailed in later sections.

This thesis will investigate how one can reduce the number of features in virtual reality, and how this affects the users of such an application. Due to the nature of exploratory research I will not aim to conclusively prove whether an interactionless VR application is valuable or not, but rather what are the potential uses, if any, of interactionless VR in education.

1.4 Research Questions

The main research question of this thesis is: **What is the potential of interactionless VR in education?** In order to answer this, three sub-questions will be posed.

RQ 1. How can an interactionless application in VR be implemented?

As there are no best practices on implementing an interactionless application VR there needs to be some guidelines for future research. This will not exhaustively explore all conceivable ways to implement such an application, but will find what aspects of this application were well suited for the application, and which were not.

RQ 2. How do users experience using an interactionless application in VR?

This research question will aim to find the subjective user experience of using the application. An important part of understanding interactionless design is understanding how it affect the user experience. Two concepts will be explored, immersion and agency.

RQ 3. What aspects of interactionless VR affect the perceived satisfaction of learners?

As perceived satisfaction is linked to how successful an educational system is, it is an important measure of how successful the application is.

For this thesis there are 3 aspects that will be explored. Guiding the users' gaze, the ease of use and how interactionless itself affect the perceived satisfaction.

1.5 Contributions

The thesis aims to fill a gap that is present in the current understanding of VR, namely that of interactionless VR. I aim to explore interactionless VR through perceived satisfaction and user experience. These factors will aim at exploring and understanding how users perceives the act of using an interactionless VR application. This study will find what, if any, potential interactionless VR has in education.

1.6 Document Structure

Chapter 2. Background Will present the research that was reviewed for this thesis. Topics include VR, education and learning programming

Chapter 3. Methodology and Tools Will present the research methodology, as well as the tools used during the thesis.

Chapter 4. Requirements Presents the functional requirements for the application.

Chapter 5. Evaluation Describes what was done in preparation for the evaluation.

Chapter 6. Results Presents the implementation, as well as the results from the evaluation

Chapter 7. Discussion Discusses the results found during the thesis, and contains a reflection on the lessons learned

Chapter 8. Conclusion A summary of the findings of the thesis.

chapter 9. Future Work Will present what avenues future researchers could take to advance the topic of interactionless VR.

Chapter 2

Background

2.1 Virtual Reality

Virtual Reality (VR) is a three-dimensional simulation, where users will usually interact with and manipulate virtual objects in a virtual environment. Predominantly relying on visual and auditory feedback when conveying information to the user, VR presents unique challenges to a developer. Many of the technical requirements for computer programs, such as framerate, are made stricter when dealing with VR. As such it is important to study and understand where the weaknesses of VR lie. Scientific literature distinguishes between to two kinds of VR: non-immersive and immersive [13]. Non-immersive VR is made for standard computers and simulate a place in 3D environment. Immersive VR, on the other hand, attempt to give users the feeling that they are physically present in the simulation. In modern times this is commonly achieved by covering the entire field of view (FoV) of the user, with a headmounted display (HMD).

Learning in VR has had very promising results. The Beijing Bluefocus E-Commerce Co. ran a study where they attempted to teach astrophysics to high school aged students using both virtual reality and traditional learning methods [8]. The results showed a drastic improvement from the students that used virtual reality, students from the VR group achieved a 90% pass rate on the test given after the experiment, while the traditional group achieved a 40% pass rate. Results like these show there lies a great potential in education in VR.

Using VR in the current timeperiod has another benefit, namely that the technology is new and novel for many users. As shown by Nadan et al. [20] students are more interested when dealing with new technologies as they ”spark their interest”. In addition Nadan et al. showed that VR was a more memorable experience (memorable meaning students retained the information better) than dealing with the same information in a lab setting. VR then is looking promising as tool for teaching, creating a memorable experience for the user.

2.2 Education

Learning has been the focus of research for a very long time, how to effectively convey information to students is seen as an important goal. Many factors have been researched in regard to how they affect education, such as socioeconomic factors, disruptive behaviour as a child [33], general intelligence and the birth order [30]. However, for this thesis I will be focusing on the factors that can be influenced, mainly perceived satisfaction and its related factors.

Effective e-Learning has been the subject of many scientific articles. Sun et al. [29] compiled a list of what previous research had unveiled about ”critical factors that affect learners satisfaction”. The paper aimed at finding which of these factors were most influential in perceived e-Learner satisfaction. The statistically most influential factors were, in order: the quality of the course, diversity in assessment, learners computer anxiety, perceived ease of use and perceived usefulness. Perceived usefulness is the degree of work improvement the system will provide, while perceived ease of use is how easy the user anticipates the system will be to adopt. Learner computer anxiety is ”an emotional fear of potential negative outcomes such as damaging equipment or looking foolish”. Diversity in assessment refers to the use of different feedback mechanisms. Lastly, the quality of the course consists of the overall course design, the teaching materials and usability, among many others. In the study the dependant variable was only learner satisfaction, and did not make use of other variables as learning performance or test scores. As such the actual learning potential of the system was not tested, however one can assume that satisfaction with a learning platform is, at the very least, loosely connected to how well users learned.

According to Nicholls research, motivation is an important factor in education [21]. Unmotivated students pay less attention, and achieve lower retention than motivated students. A key aspect of this finding is the difference between endogenous and exogenous reward. Endogenous, or intrinsic, comes from within, meaning the task is itself rewarding, and is considered the most important of the two. Exogenous, or extrinsic, comes from the outside, the task is a means to an end, and correlates to lower levels of motivation. However, creating intrinsic rewards for others requires extensive effort and could even necessitate changing that persons entire view of a task, and in some cases may simply be impossible. Extrinsic rewards on the other hand, are far easier to create, giving a reward upon completion of a task is naturally far easier than changing someones attitude.

Attribution theory [34] presents ability, effort, task difficulty and luck as the main attributes people use to explain success or failure. Ability and effort are internal factors, while task difficulty and luck are external. In the original 1972 paper Weiner believed that effort was the more motivating of the two intrinsic factors, but later research suggests that ability may lead to higher levels of motivation.

2.3 User Experience

User experience (UX) is the subjective experience of the user interacting with a piece of software. While many factors influence user experience, there is no consensus on exactly how to define the concept [18]. It is generally understood that user experience is dynamic [32], where a user can try the same product at different times and experience it differently. This makes measuring user experience a difficult task indeed.

In this thesis the main focus of the user experience will be a bit unconventional. Due to the way the application is structured there are two factors that are critical to gather regarding the user experience: immersion and agency. Immersion in regards to VR refers to the degree that users feel that they are physically present in the VR application. Agency in this thesis refers to the degree with which users feel that they are able to control and act in the application.

2.3.1 Immersion

Immersion was defined by Jennet et al. [16] as a "lack of awareness of time, loss of awareness to the world, involvement and a sense of being in the task environment". With this definition in mind, looking at immersive VR there are there are two key factors, HMD and the motion tracked controllers. The HMD of a modern VR device, such as the Oculus Rift or HTC Vive, cover the entire FoV of the user. This will in essence separate the user from the rest of the world, replacing it with a digital simulation. Visual distractions from other sources will be limited, and the user will have a greater opportunity to achieve immersion. The controllers allow the user to "physically" interact with elements of the simulation, by using real-world actions to interact with the digital environment. However, these two factors alone are no guarantee for immersion, there are many other factors that can influence how immersed a user feels. Jonathan Steuer [28] proposed two critical factors of immersion: breadth of information and depth of information. Breadth of information is the "number of sensory dimensions simultaneously presented", a system that engages all the senses of the user would have a wide breadth of information. Depth of information refers to the amount and quality of data a user receives, such as the graphics of the environment, display resolution, etc. In addition, there are a wide variety of other factors that can positively or negatively influence a users immersion.

Research has shown that users being immersed can lead to greater learning benefit [9]. Among the topics discussed in Dede's article is the perspective the users have, differing between an egocentric perspective and an exocentric perspective. These perspectives are noted as having different learning benefits, where egocentric gives actional immersion and motivation, while exocentric provides more abstract, symbolic insights. Dede states that immersion is increased when the application is able to combine actional, symbolic and sensory factors; in essence making the user forget they are in a virtual environment. While difficult in this instance to implement well due to time and budget constraints, striving for high immersion is vital for a VR application. However, many aspects of immersion are implemented simply by the application utilizing a HMD, such as actions corresponding to real-life actions and putting the user in an egocentric perspective. However, to increase the learning benefit the application is structured to provide the users both perspectives. Wherein the PoV is from the user utilizing an egocentric perspective. While the executing code will be set a fair distance from the user allowing an exocentric perspective.

One of the challenges facing computer science in VR is that programming is inherently an abstract task. Programming is done behind a computer screen on a keyboard, something that does not seem to warrant VR usage. However, where VR shows potential is in visualizing how computer code executes. By using 3D models in the virtual environment one could show a for-loop being executed with corresponding actions happening in the environment. In addition, one would be able to display the hidden internal changes that are used by many programming concepts.

2.3.2 Agency

Whether users feel a sense of agency is rarely a factor that is explored in computer science. While there are many reasons for this, the most prominent is the fact that it is seldom necessary to inquire about whether a user felt they had agency while using an application. However, this application will be interactionless, and as such whether the user has a sense of agency could be affected. Haggard defines sense of agency as [14] : ”The experience of controlling one’s own actions, and through them, events in the outside world”. This defines two key components of agency: the experience of controlling one’s own actions, and those actions affecting a system not directly under the control of the actor. The definition of agency as used in this thesis was inspired by this definition, the thesis defines agency as: ”the experience of controlling one’s own actions, and through them, the application”. This maintains the two key components from Haggard’s definition, while also narrowing it down to focus on the application.

However, it is difficult to measure agency [14]. But, I argue that for user experience it is not necessary that users have actual agency, it is far more important that they *felt* they had agency.

2.4 Learning Programming

Learning programming has historically been viewed as challenging and as such, much research has been done on the topic. du Buboulay [10] separated the difficulties facing novice programmers into five areas, with some degree of overlap between them. First is orientation, relating to what programming is for, what can be achieved with programming and why one should expend the effort in order to learn programming. The second are the general difficulties in understanding the general principles of the computer, understanding the notional machine, and how the notional machine relates to the physical machine. Thirdly, the notation of the languages needed, such as the syntax of the programming language and the underlying semantics. The fourth is the difficulty of acquiring a set of standard structures, or plans to achieve sub-goals, such as calculating a sum with a loop. The final difficulty is acquiring the skill set needed to specify, develop, test and debug a program using whatever tools are available. As du Boulay states, these difficulties are exacerbated by the fact that these skills are not entirely separated, meaning novice programmers will face these areas of difficulty at the same time.

In addition, there are three areas of knowledge a user must have in order to construct a program [5]. Syntactic knowledge, relating to knowledge of specific facts about a programming language, and its rules for use. Conceptual which concerns itself with the constructs and principles of computer programming in general. And finally, strategic which are the general problem-solving skills which are programming specific. Syntactic knowledge is needed in order to gain experience in conceptual knowledge, while you can learn what a for-loop is, without syntactic knowledge you cannot create one. Strategic knowledge is dependent on both syntactic and conceptual knowledge, as you will need both in order to implement the strategies. There are two notable approaches to gain this knowledge [22]: move the user closes to the system, e.g. teaching users how a computer ”thinks”, and moving the system closer to the user, e.g. making the system more human friendly. The former method is the most commonly used in education.

The differences between the mental model and the physical machine in novice programmers can, and often will, conflict which can result in believing certain actions are permissible when they are not, and vice versa. This is further exacerbated by the fact that the computer operates as a blackbox, where users are only able to view the input and output. The crucial middle step in how the computer handles the input is, inconveniently, left out, making errors in the program that much harder to find and fix. As stated by Satratzemi et al. [27] ”the lack of visual feedback makes the understanding of language semantics hard”. When looking at what programming concepts novice programmers are struggling with, there is a trend among these concepts. They will usually involve hidden internal changes, such as the control variable in a for-loop [10].

One final note are the different type of novice programmers. Some will understand programming quite quickly, while others will struggle with it for a long period of time and may even abandon programming. Robins et al. [25] compiled a list of what factors have been examined in order to gauge how successful a novice will be. General intelligence was found to be one of the only measurable factors related to success. However, other factors such as cognitive style and personality seem to have little impact. Robins et.al had conducted a study the previous year [24] that covered other factors, such as background, intended major, how interested they were in CS, amongst others. They found that the best predictor was what grade the student expected to get, with higher grades expected correlating to a higher grade achieved in the course. It is important to note that the students were asked after only attending the CS course for two weeks. This indicates that students are able to tell early how likely they are to succeed.

Learning to program, as noted, is considered difficult; there are many topics that need to be understood in order to be a capable programmer. These range from the semantics of a specific programming language, all the way up to the strategic plans that need to be implemented to get the program working properly and everything between. To make matters worse, these skills will need to be developed concurrently as these are not independent topics. There is a degree of overlap between these topics, and the knowledge gained in one topic will be necessary in order to understand a different topic. Essentially if a novice programmer does not understand or is struggling with one of these topics it could severely hinder development in the other topics. In this project I aim to help novice programmers with some of the earliest hurdles they need to overcome, namely understanding how some of the essential programming concepts work.

2.4.1 Visualization

Much research has been done on the topic of the problems and origins of the difficulty in learning programming. One theme present throughout most studies is that users are only able to view the input and output when programming. The rest is hidden from the user, making it harder for learners to perceive and understand what steps are taken when a program is executed. And this is the focus of my study. In VR I will be creating a visualization of some of the key programming concepts that many novices are struggling with. By programming concepts I refer to both statements such as the for-loop and if-then-else, as well as problem solving methods such as recursion. VR is uniquely suited to this task for two reasons. First and foremost is the presence and immersion that VR provides, users will be able to study the execution while feeling that they are in the presence of this happening. Second, is that VR has been shown to more memorable than other settings such as a lab setting [20]. These two aspects should make this both a fun and educational setting for users.

Due to the lack of any visual feedback on how the computer handles input and generates output, novices are often introduced to analogies. While analogies can certainly be useful, novices can sometimes extract more information from them than is warranted [10]. This can further increase the difficulty in learning to program, since the novice is now using wrong information to create, test and debug their programs. However, there are other methods that also attempt to impart knowledge on the user. Such as the notional machine and general models of control, data structures, data representation, etc. Design and use of visual systems naturally focuses on practical experience, opportunity for novice programmers to abstract the concepts and principles of programming [5]

As noted in previous sections there are many challenges facing novice programmers in their quest to become accomplished programmers. And just as with what challenges are facing novice programmers, much research has been done on the topic of how to alleviate these challenges. There are different approaches in how this can be achieved, the most relevant approach for this paper are the ones that focus on visualizing. Visualizing can roughly be divided into two categories: visualizing programming concepts such as recursion or loops, and visual programming environments such as AnimPascal [27]. While there is certainly a degree of overlap between these two approaches, the difference lie in their goals. Visual programming environments commonly attempt to aid students in creating, debugging and testing their program. While visualizing the concepts aim to give the user a deeper understanding of a single or several concepts. As visualizing concepts is the aim of my program as well, this is what I will concern myself with in this section.

Wu et al. [35] attempted exactly this with their SimLIST and SimRECUR programs, where users would be able to create their own linked-list and recursive program respectively. Both programs were visual programs, where users were able to track all changes in the internal state throughout the operations available to users. The results from their study was promising, where 93% of respondents believed they had a better understanding of the linked-list structure than before they tried SimLIST. SimRECUR was not tested in a lab setting in this paper, but in their previous paper [36] they did a field test to get preliminary results on whether it was effective or not. The test showed students did indeed know more about recursion than before they started, and 84% believed SimRECUR had given them a deeper understanding of recursion. This shows that visualizing concepts can be an effective way to have novices programmers understand these concepts.

Rudder et al. [26] created a web-program that is aimed at teaching younger students(aged 14-17) the programming concepts of if-then-else and while-loops. In this program they use real-life examples to explain how these concepts work, such as buying a bike IF the character has enough money. The program consists of two parts, first is the demonstration which is the visual part, this is followed by a problem the user has to solve using the knowledge gained by the demonstration. The results showed that students enjoyed the visual experience, and understanding of the concepts were reinforced. Which further shows that visualizing single concepts can be an effective method. However, while the conclusion of the paper say that the program was evaluated by students, teachers, and instructional designers, only the students evaluation was explicitly presented in the paper. This does not necessarily mean that teachers and instructional designers were not positive towards it, but it does reduce the credibility of the program as a teaching tool. Further research is needed.

Chapter 3

Methodology and Tools

When designing IT systems and applications for research it is vital that a proper research methodology be chosen. These should reflect the nature of the task at hand, as well as provide a solid foundation for the work. This chapter will detail the methods used during the thesis, as well as the tools used.

3.1 Research Methodology

The research methodology was based on the model Oates presents in his book *Researching Information Systems and Computing* [23], as pictured in Figure 3.1. In the figure if a box is outlined as red it was used during this thesis.

3.1.1 Research Strategy

The research strategy chosen was design and creation. Design and creation (D&C) is a research strategy that focuses on developing new IT products, called artifacts [23]. D&C in and of itself does not necessarily create knowledge, and in my case it does not. To generate new knowledge it is imperative that the users of the system be observed using it and asked questions about their experience during the evaluation.

As the de facto research strategy for the creation of IT artifacts, the choice fell quickly on D&C. As a researcher there were two main benefits to using this strategy. First and foremost is that designing IT products for research purposes is quite different from commercial or hobby development, and D&C provides a framework from which to base the application on. One part of the framework is the previously mentioned iterative process, the other is the evaluation stage of the iterative process. D&C provides an evaluation guide and having access to this when it comes to evaluating the design is invaluable. The second

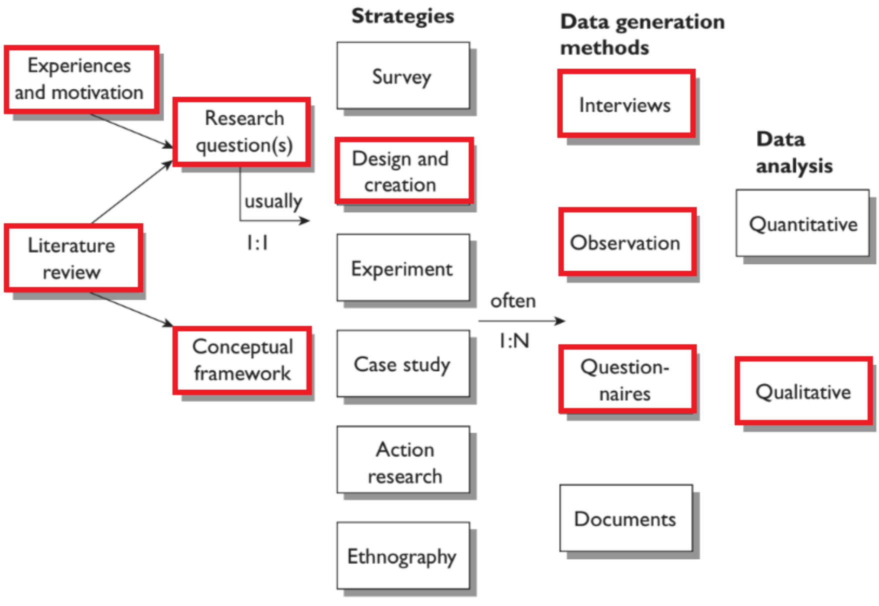

Figure 3.1: Research Methodology

benefit is that it encourages a certain frame of mind where the focus is not on the product in and of itself, but rather the artifact; the area of new knowledge.

3.2 Data Generation Methods

A pre- and post-questionnaire was used. These were created using a 5-point Likert scale, ranging from 1 - strongly disagree, to 5 - strongly agree. The statements on the questionnaire were greatly influenced by the questionnaire used by Sun et al. [29] to find perceived satisfaction and related factors. After the user had concluded the questionnaire portion of the test, a short semi-structured group-interview was held. This was to allow for users to discuss things that were not on the questionnaire. As the main research question is aimed at finding the user experience, it was necessary to allow the users to share attitudes and perceptions that were either not expressed in the questionnaire or not expressed thoroughly enough. Lastly during the test of the application the author observed the participant taking note of how long a user would spend in each scene and what problems the user encountered. This was important for the interviews, since if anything interesting were to occur it could be discussed.

3.3 Data Analysis Methods

The data analysis methods used were primarily qualitative. Both content and narrative were analyzed in order to further understand the various aspects of the interactionless application, and how they affected the participants. Participants would be categorized based on two factors, experience with programming and experience with VR.

3.4 Requirement Elicitation

The requirements for the application were mainly elicited from two sources, brainstorming sessions and literature review.

3.4.1 Brainstorming

There were three different brainstorming sessions that were commonly used during the development of the application. The first one was with the supervisor, where the design and implementation was discussed. These sessions provided much of the baseline functionality for the application. The second type was in discussion with another student who have a similar product to mine. These discussions were focused on what parts of programming were to be implemented and how it would be presented to users. The last kind of sessions were group discussions in the VR lab, those involved were 3 other students who have a VR master's thesis. During these all the students would present what they had worked on, and what their plans were. These discussions allowed the students to give feedback to each other, and provided helpful tips for future development.

3.4.2 Literature Review

As has been mentioned a few times by now, there are no similar products. This means that there are no best practices when it comes to designing this specific implementation. However, there are still many aspects of the application that have relied on previous research and best practices.

Of note is the execution of the VR environment. The biggest contributor to this section was the Unity Development Guide for Virtual Reality [2]. This does not only contain helpful tips for what elements one should include and avoid in the application, but also general information on how to implement functionality, or which graphics options are suited for VR. In addition, a guide on Oculus best practices [1] were used. These helped in shaping the requirements of the application, as there are many technical aspects of VR to keep in mind while developing for it. However, the technical aspects are not the only parts of the application that require thorough research in order to adequately implement. The application also took inspiration from previous research that had attempted to create and research similar applications, the literature used is described in chapter 2. Note that none of these are VR-applications.

3.5 Requirements

Based on the requirement elicitation the following requirements were created.

ID:	FR1
Title:	System should guide the users gaze
Desc:	The system should use color and color change to direct the users gaze to where they should be looking.

ID:	FR2
Title:	User must be able to view both the executing code and the corresponding actions
Desc:	While the user is engaged with a visualization they must be able to simultaneously view both the executing code and the actions that take place as a result of the code.

ID:	FR3
Title:	The system should be accessible for players of different levels of VR experience
Desc:	The application should be usable by both users that are experienced in VR and users that have little to no experience with VR.

ID:	FR4
Title:	Users shall be able to start the application without interacting with in-game elements.
Desc:	When a user wants to start the execution of code this shall be done by pressing a button on the controller

ID:	FR5
Title:	System must change the color of executing code
Desc:	When the system is visualizing a programming structure, the color of the text must change according to how far the code has executed.

ID:	FR6
Title:	A demonstration should have at least two different examples that users can view
Desc:	When viewing a demonstration of a programming concept it should be at least two different examples that users can view.

ID:	FR7
Title:	User should be able to change the time-interval between actions in a demonstration
Desc:	When the system is going through a demonstration the time between actions might be too quick or too slow for some users, as such they should be able to change how long it takes for the system to move to the next step in the demonstration.

ID:	FR8
Title:	Users must be able to change the speed without interacting with in-game elements
Desc:	When a user wishes to change the speed of the application this must be done with the controllers.

3.6 Revised Requirements

As is common in software development the requirements were constantly updated and revised. A number of requirements were added at a later point in the study, but ultimately removed as they would increase the scope of the thesis by a large degree. However, one of the original requirements that were presented in section 3.5 was intentionally not implemented. FR6 stated that two different examples should be implemented. This was to test the hypothesis that this was one of the benefits of interactionless VR, e.g. lower development time. However, as there are no applications available to compare these results to, it was decided that this requirement would not be realized. To see the full table of which requirements were implemented see appendix B

3.7 Intended Audience

This application will be aimed at novice programmers who have recently begun programming. The programming concepts that will be visualized are introduced early when learning programming, due to how vital they are in software development. Most experienced programmers will have intimate knowledge of these concepts, and as such will have little use of this application personally. There is a possibility that users with no previous knowledge of programming could learn from this application, though there is one barrier to overcome in order for that to happen. It was difficult to provide the user more information than what the game is visually capable of delivering, e.g. there will be no voiceover to explain a concept during the execution, only the executing code with its corresponding visualization. This means that a user will likely need to have some preexisting knowledge in order to gain something from the application. However, this is something that will be tested, to what degree users with no experience in programming are able to use and learn from the application.

3.8 Evaluation Planning and Execution

The plan for the evaluation was to give each participant one session lasting approximately 45 minutes where they would be able to use the application. Participants from different backgrounds were invited to the VR lab to evaluate the application. Participants were free to choose a time when they would be available to take part in the evaluation. Before each evaluation participants were asked to fill out a pre-questionnaire where they were asked about their previous experience with VR, and their perceived competence in programming. After they had tried the application they would take a post-questionnaire focusing on their subjective experience of the application. And to finish the evaluation, a short interview was held to gain insight in aspects that may not have been covered by the questionnaires.

3.8.1 Participants

There were nine participants, with eight students and one non-student. All participants were in the age group 22-27, whereas six participants were women and three were men. The participants of the evaluation were mostly students from NTNU, with different backgrounds. Students with background in Math, English and IT were invited. Most of the participants had little to no previous experience with VR, and perceived competence in programming ranged from none to expert. This mix of experiences proved valuable in the evaluation, as there are clear trends among users both in regards to previous VR experience and competency in programming.

3.8.2 Pre-Questionnaire

The pre-questionnaire consisted of 4 questions and was used to gain an overview of participants background in VR and programming. Participants were asked to rate their competence in programming before trying the application in order lessen the potential bias that could be present were they to be asked after the fact.

The questions consisted of three with radio buttons, allowing only one answer, while one question had checkboxes to allow participants to check the applicable answers. A five-point Likert scale was used, with answers ranging from strongly disagree to strongly agree.

The first question was relating to the participants previous experience in VR, asking how many times they had used VR. The follow-up question was which kinds of applications they had used(*games, video, education, others and none*). After that participants were asked whether they believed VR could be used for education, on a Likert scale. The last question was how competent they considered themselves in programming, also a Likert scale.

3.8.3 Using the application

After a participant had filled out the pre-questionnaire they were directed to the VR station were they would use the application. Participants were given a brief overview of what actions they had at their disposition, and the purpose of the application. After this was done the evaluation began. Users would go through the application linearly, beginning in the first scene with variables, moving to conditionals after that, then to for-loops and ending with recursion. This was done to ease participants into programming, as each new concept is more complex than the last, and would generally require an understanding of the previous concept. During the evaluation they would be observed in order to gain an understanding of the usage, and what, if any, problems occurred.

3.8.4 Post-questionnaire

With the test completed participants were asked to fill out a post-questionnaire. This questionnaire consisted of 21 questions on a 5-point Likert scale, and one checkbox question were participants were asked to list any physical discomfort they felt during the test.

The questions were mainly centered around perceived satisfaction, and the factors that Sun et al. [29] related to it. The first section of the questionnaire pertained to participants perceived ease of use.

Perceived Ease of Use

The questionnaire opens with 4 statements on the perceived use of ease, or usability, listed in Table 3.1. These are grouped in order to keep the participants focused on this area, and it was the first section of the questionnaire to get the feelings related to the usability while fresh. These statements were asked to gather data on RQ1, RQ2 and RQ3.

ID	Question
PE1	I thought it was easy to use the application
PE2	I thought it was easy to achieve what I wanted in the application
PE3	I believe most people could learn how to use the application
PE4	I thought it was cumbersome to use the application(R)

Table 3.1: Perceived ease of use statements

Course Quality

As the most significant factor that Sun et al. [29] linked to satisfaction it was vital to gather data on this point. These questions can be viewed in Table 3.2. They are centered around the learning content of the application, and to what degree they understood the content and its purpose. While course quality was not the focus of this thesis, if the course quality was low in the application, this would affect satisfaction negatively. As such it was vital to gather information regarding the participants response to the course quality. These statements finds information related to RQ3.

CQ1	I thought the information presented in the application was unclear (R)
CQ2	I thought the quality of the learning content was high
CQ3	I thought the theme(programming) was a suitable topic for the application
CQ4	I felt the visualization helped me understand the concepts presented in the application

Table 3.2: Course quality statements

Perceived Usefulness

These questions,Table 3.3, were related to the perceived usefulness of the application, and specifically what factors affected the perceived usefulness. These statements pertain to RQ1 and RQ3.

PU1	I thought it was useful that the text in the application changed color
PU2	I thought it was useful that the elements of the game changed color
PU3	I thought it was useful that I was able to change the speed in the application
PU4	I thought the application was useful to understanding programming

Table 3.3: Perceived usefulness statements

Perceived Satisfaction

This section looked at the general satisfaction of the participants, as well as how the lack of interaction affected the satisfaction of participants. Table 3.4 shows the statements. As this is the very thing RQ3 is focused on, it was imperative the questionnaire contained statements relating to satisfaction.

PS1	I would like to learn more about programming in a similar application
PS2	I would like to learn about a different topic in a similar application
PS3	I believe the lack of interaction helped me focus
PS4	I feel I had too little control over what happened in the application (R)
PS5	I greatly enjoyed having low amounts of control over what happened in the application

Table 3.4: Perceived satisfaction statements

Computer Anxiety

As the only factor found by Sun et al. to have a significant negative correlation with perceived satisfaction, it was important to include this on the questionnaire. Add to this, that VR is not yet mainstream could conceivably increase the computer anxiety the participants might feel. These statement pertain to RQ3.

CA1	I felt anxious before trying the application
CA2	I was afraid I would look foolish while using VR
CA3	I was afraid of destroying the equipment while using the application
CA4	The application made me feel physical discomfort

Table 3.5: Computer anxiety statements

3.8.5 Observation

During the test participants were observed in order to gain an understanding of their usage pattern. Among the key measurements to observe was time spent in each scene, and to what degree users would change the speed. In addition, any problems the user would meet were noted, and if anything notable were to happen it would be discussed during the interview. The observer guidelines were taken from the usability research from the Nielsen Norman Group [12].

3.8.6 Interview

The interview was held in order to gain an understanding in areas that could not be adequately asked in the questionnaire, new aspects that could occur during testing, and the opportunity to have participants explain more in-depth their subjective feelings regarding the application. This is a common use of interviews [11].

3.9 Tools

In this section the tools used during the thesis will be discussed.

3.9.1 Unity

Unity was the only tool needed to develop the application, and as such is the only tool of importance used during the thesis. Unity is a popular game engine, and is currently the most used development tool for virtual and augmented reality, powering over 60% of VR and AR applications [3]. While Unity provides much functionality to users, in order to create custom functionality, developers need to create scripts. These scripts are written in C#. Unity contains native support for development in Visual Studio, though other IDE's can be used.

With Unity the application can be both debugged and ran directly through the program. While it is possible to package the game and run it on other computers, due to the lack of available VR devices the testing was conducted on the computer where the application was developed. Additionally, Unity supports cloud storage which is very important when developing an application for a master's thesis.

As Unity provided everything needed to develop a VR application, no other tools were used to develop the application.

3.9.2 Other Tools

While of no great importance to the research, or otherwise, other tools were used during the thesis and for the sake of posterity will be quickly presented in this section.

Visual Studio The IDE used to write the computer code for the application.

Overleaf Used to write the document for the thesis.

Google Forms Used to create the questionnaire.

Google Drive Used to mange the files and important documents for the thesis.

Google Scholar Used to find the relevant literature.

Chapter 4

Results

This chapter will present the results from the thesis. Both the implementation and the results of the evaluation will be discussed.

4.1 Implementation

This section will detail the implementation, design choices and what elements are present in the application. A demonstration of the application can be viewed at `https://youtu.be/yisLvPxRBDU`

4.1.1 Functionality

While using the application users have four different actions available to them: starting the demonstration, increasing the speed, decreasing the speed and moving to the next scene. These are executed by pressing the associated button(s) on the controllers. This will maintain the intent of the design, as users are not able to interact with any of the in-game elements of the application. Instead they are only able to remotely control when to start a demonstration and the speed at which it executes, as well as when to move to the next scene.

4.1.2 Feedback

Each scene has a different feedback mechanic. This was in order gain a wider understanding of what feedback mechanics are effective in interactionless VR. An important aspect of this, is that users of this application are the ones who must decide whether to advance to the next scene or not. The system will not force users to progress, and as such the feedback mechanics should reflect this. The details of the feedback mechanics used in each scene will be further explained in section 4.2.

4.1.3 Elements of the application

For the sake of simplicity I will be presenting a brief overview of the various elements in the application. An overview of which elements are present in which scenes can be seen in Table 4.1.

Blackboard

The blackboard pictured in 4.1 is the focal point of the application. The actions happening around the user is explained by this, and as such users will, hopefully, spend the majority of their time looking at it. The text of the blackboard will change color based on how far the code has executed, pictured in 4.2, as well as certain events happening, i.e. the if-condition was either true or false. The line being currently executed is shown in yellow, while a conditional returning true becomes green, and red if it is false, this was done to fulfill FR1. Red and green was chosen as they are commonly associated with rejection and acceptance, or in this case whether it was true or false. Yellow was chosen because it has a high enough contrast from the black background and remaining white text that it is clearly visible.

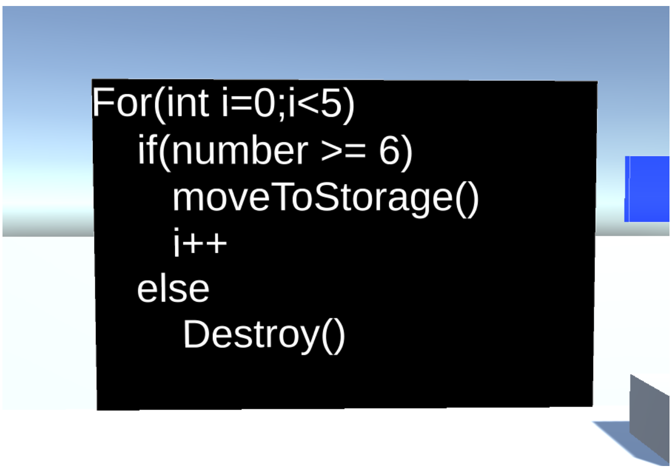

Figure 4.1: The blackboard in the for-loop scene

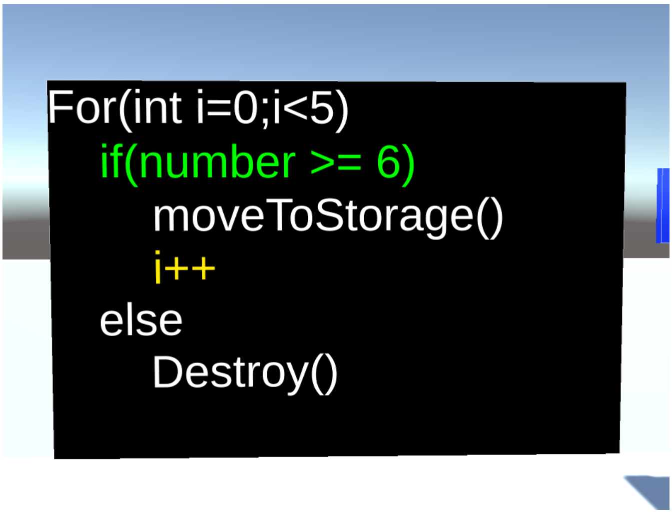

Figure 4.2: The blackboard showing the progression of the code.

Number Cubes

Cubes, pictured in4.3, were used to represent variables in the scenes. The actions of the executing code is performed on these cubes. As with the text, the color of the cube is changed when it is used by the system, as can be seen in figure 4.4 and the result in figure 4.5.

Figure 4.3: A cube with a number

Counter

The counter pictured in 4.6 was only used in one scene, the one containing the for-loop. This was to allow users to keep track of what iteration the loop was currently in, as well as giving an indication of exactly when a counter in a for-loop is updated.

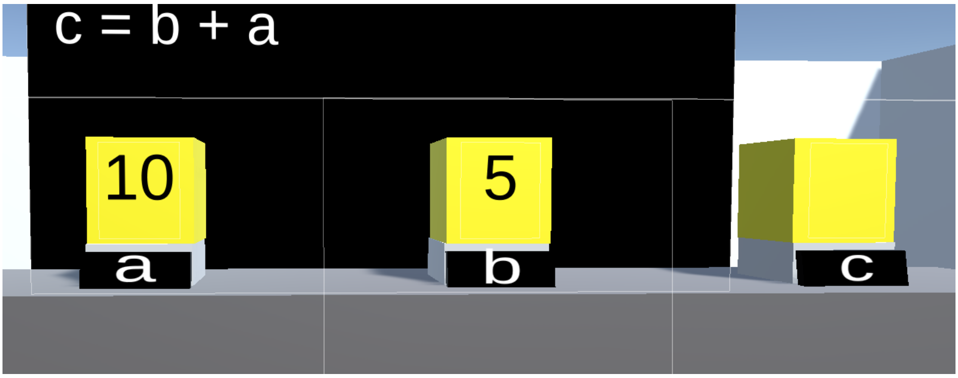

Figure 4.4: Cubes while the system is using them

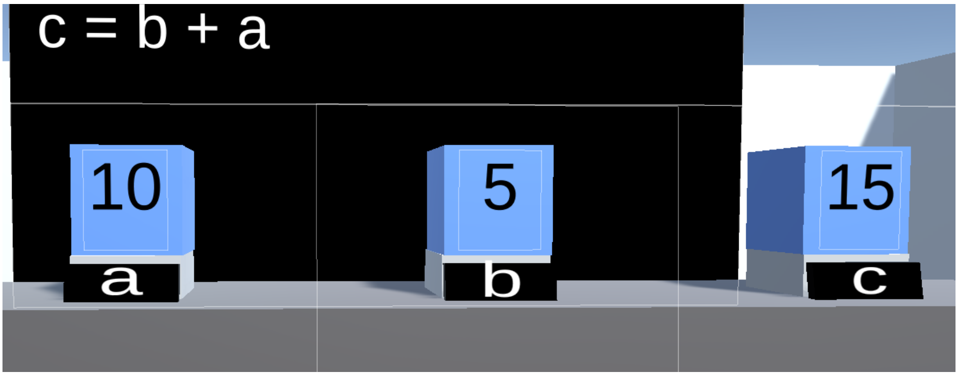

Figure 4.5: After changes have occurred

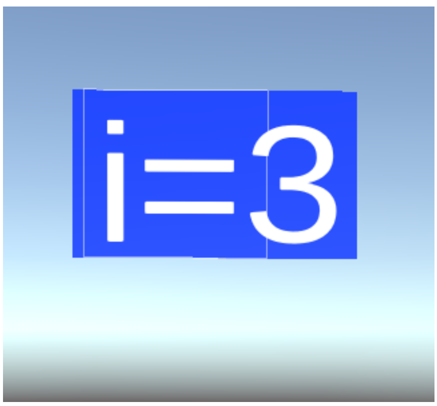

Figure 4.6: Counter

Scene	Blackboard	Number Cube	Counter	Speed Tracker
Variables	Yes	Yes	No	No
If-Else	Yes	Yes	No	Yes
For-loop	Yes	Yes	Yes	Yes
Recursion	Yes	Yes	No	Yes

Table 4.1: Table showing what elements are present in each scene

Speed Tracker

The speed tracker, seen in Figure 4.7, was used to give users a visual indication of the current execution speed. Users can increase and decrease the speed the of executing code in the application, and it was necessary to give a visual indication of what the current speed is.

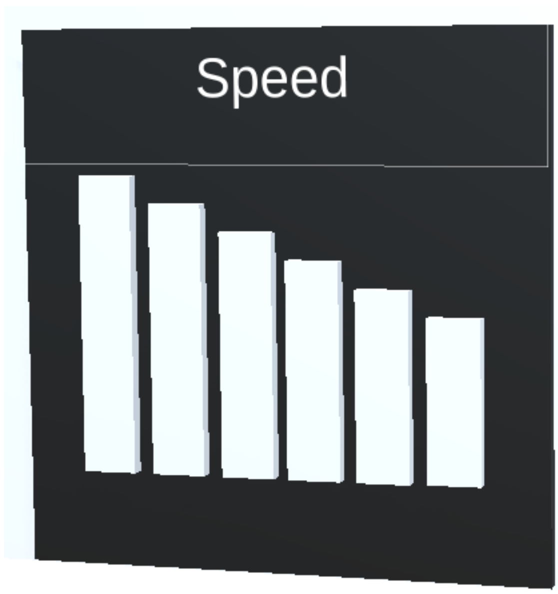

Figure 4.7: Speed tracker

Help Sign

In order to reduce confusion and to allow the test to be conducted without outside help, a help sign was included in each scene. This can be seen in Figure 4.8. This was a simple remainder of what button did what.

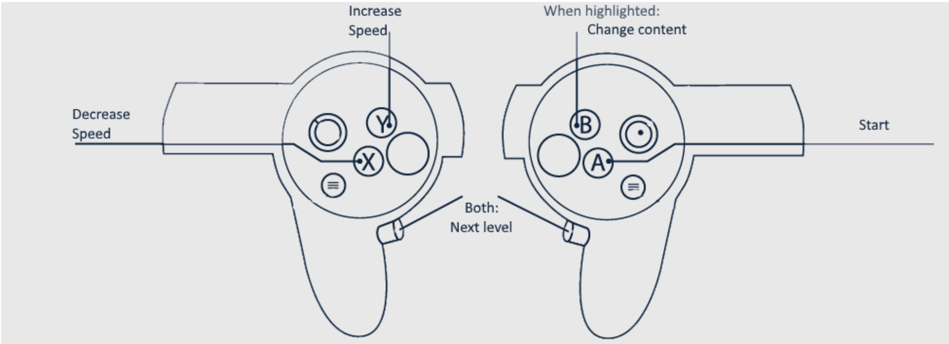

Figure 4.8: Help sign

4.2 Scenes

The application contains in total 4 different scenes, exploring the concepts: variables, conditionals, for-loops and recursion.

4.2.1 Variables

In the first scene users are introduced to variables, seen in Figure 4.9. The examples shown are made to be simple, showing a few use cases of setting and retrieving variables. This was scene was created in order to give the users with no previous programming experience a rudimentary understanding of variables, which will be important in the later stages of the application. This is the only scene to not feature highlighted text on the blackboard. This was due to the fact that the line of code being executed is only one line long, and is also placed on the bottom of the blackboard, making it clearly visible. The feedback mechanism implemented in this scene, consists of the text on the blackboard flashing green and white for approximately 2.5 seconds.

4.2.2 If-else

This scene contains a single example of an if-else statement being executed(Figure 4.10), checking whether a number is larger than or equal to six. While if-else is usually not considered a large obstacle for novice programmers, the same 'if-else' is used in the following scene that contains a for-loop. This aims to help novices ease into for-loops, using a statement that they are already familiar with. This scene contains no feedback on when a user has completed the scene. There are two reasons for this. The first reason was that it would be interesting to explore how important feedback mechanisms are in an interactionless VR application. The second reason being that the scene can be considered complete after only one iteration, there are no significant changes after the first iteration. This meant that this scene was the perfect example to explore how important feedback mechanisms are.

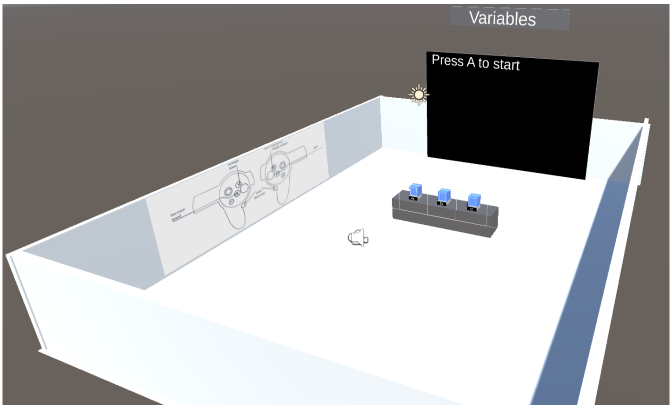

Figure 4.9: Overview of variable scene

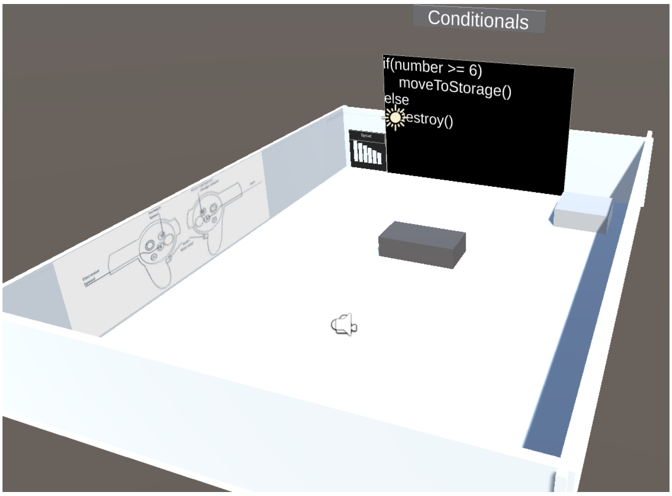

Figure 4.10: Overview of if-else scene

4.2.3 For-loop

In this scene there are two different implementations of for-loops, one implementation can be seen in Figure 4.11. One is what could be considered the traditional for-loop where the counter is incremented after every loop, terminating after five iterations. In the other implementation the counter is only increased under certain circumstances; in this example the counter is increased when the number is larger than six. The loop is iterating the same conditional from the if-else-scene. This was done to reduce the amount of information the user has to process, by reusing code users will already be familiar with. In addition to the previous elements, this scene adds a new element in the form of the counter-tracker. This allows user to keep track of when the counter is increased, as well as what the current value of the tracker is. When the loop terminates a small segment of the text is highlighted as green. As opposed to the feedback used in the variables scene, this green text remains on the blackboard until the user either advances to the next scene or restarts the code. One could also argue that the counter incrementing to 5 is a form of feedback.

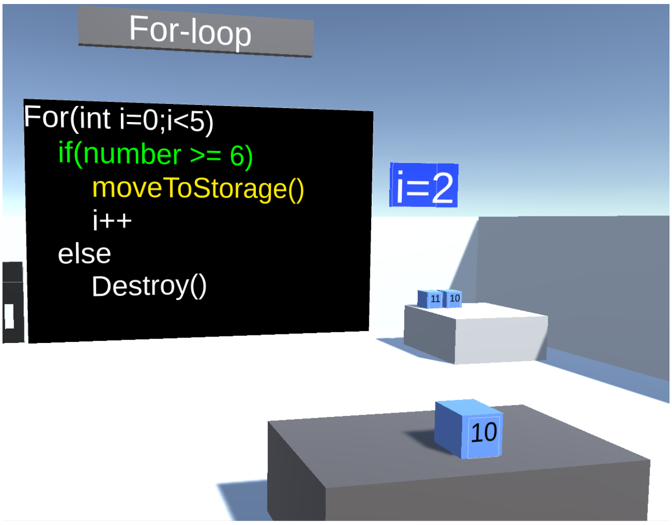

Figure 4.11: For-loop in mid-execution

4.2.4 Recursion

The scene contains an implementation of the Fibonacci sequence, seen in Figure 4.12. The Fibonacci sequence is a classical problem that can be solved with recursion. The sequence executes until the larger of the two numbers being added in the sequence exceeds 55. This number was chosen semi-arbitrary, the number would need to be large enough that the code would be executing a sufficient amount of times before reaching the base case, but also not so large that it would become tedious. While it is common to instead reach for the nth number, this was too similar to the previous scene containing the for-loop. The feedback mechanism on this scene is based on the recursion reaching its base case, where the loop will terminate.

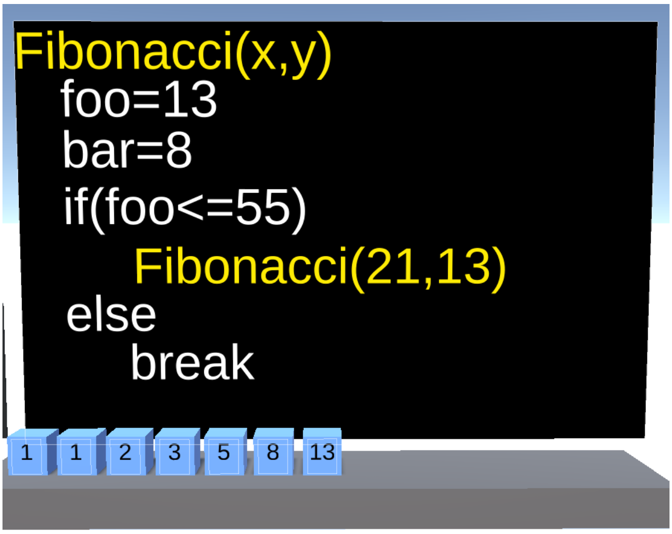

Figure 4.12: The fibonacci in mid-execution, showing how the method calls itself

4.3 Evaluation Results and Analysis

This section will present the results of the evaluation, beginning with the pre-questionnaire, and then the post-questionnaire. Lastly the results from the interview and observation will be presented. On the figures presented in this section there numbers correlate to the Likert scale as such: 1 - strongly disagree, 2 - disagree, 3 - neutral, 4 - agree, 5 - strongly agree

4.3.1 Pre-Questionnaire

This questionnaire aimed at finding background information about the users, relating to their experience in VR and competence in programming. Most participants in the evaluation had previous experience with VR. Of the 9 participants, only two had never tried VR before. The full answers can be seen in Figure 4.13.

Of the participants who had tried a VR application before, game was the most popular application type, with education a distant second, see Figure 4.14.

The attitude towards education in VR seems to be very positive (Figure **??**, with 8 out of 9 strongly agreeing with the statement that VR can be used in education, and 1 that simply agrees. This shows that none of the participants had a negative bias towards education in VR, however a positive bias is a possibility.

There was a wide variety of perceived competence in programming, as can be seen in Figure 4.16. Having participants with a variety of backgrounds was important in order to gauge whether the implementation had been successful. If the application is only usable by participants with high perceived competence, or it requires previous experience with

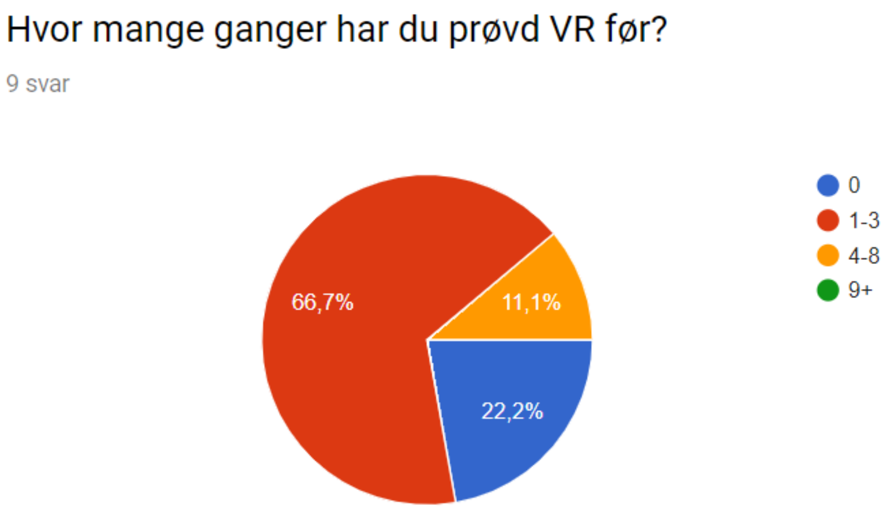

Figure 4.13: Previous VR experience of participants

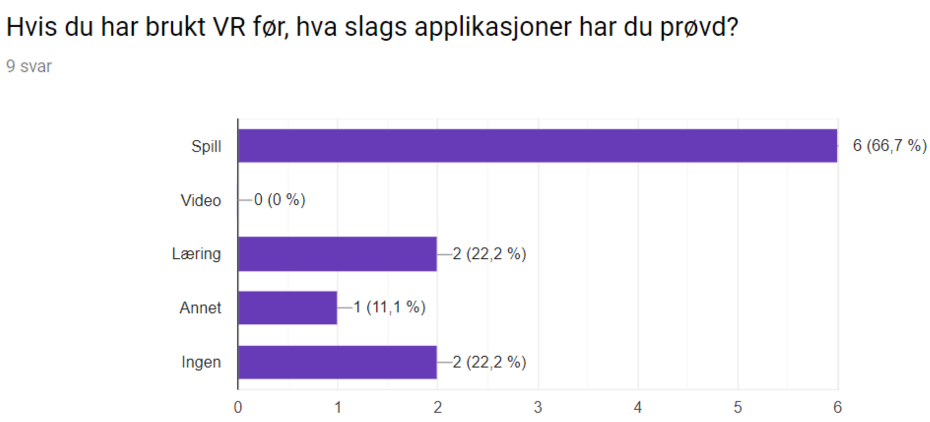

Figure 4.14: Type of VR application participants had tried

VR the viability of the product is greatly diminished. In addition, with this data measures can be taken on what their experience was, in conjunction with their background, to see what differences, if any, are present.

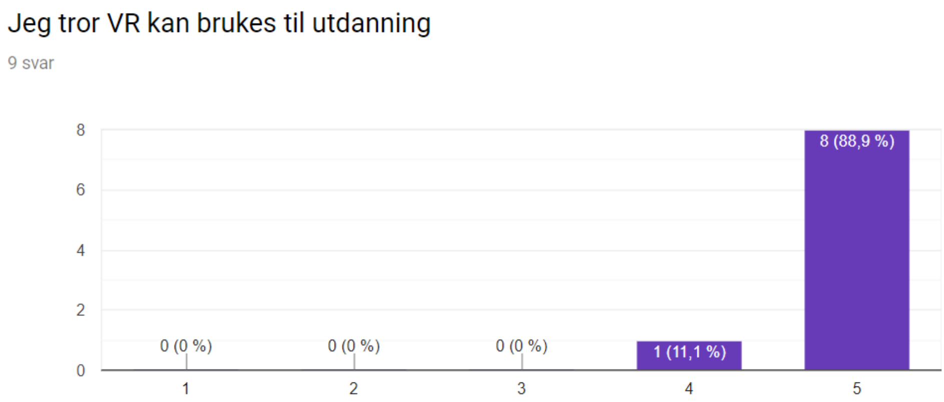

Figure 4.15: Participant attitude towards education in VR

Figure 4.16: Perceived programming competence

4.3.2 Post-questionnaire

This section will present the results from the post-questionnaire, it is divided into the five sections from the questionnaire. The full results can be seen in appendix A.

Perceived Ease of Use

PE1: I thought it was easy to use the application Most participants found the application easy to use. As the application has very few actions available to users it was expected that most participants found it easy to use. However, as can be seen in Figure 4.17, one participant did not find the application easy to use. The one participant that disagreed with that statement might have encountered a problem with either the feedback in the application, or how to progress from one scene to the next(more about this in section 4.4).

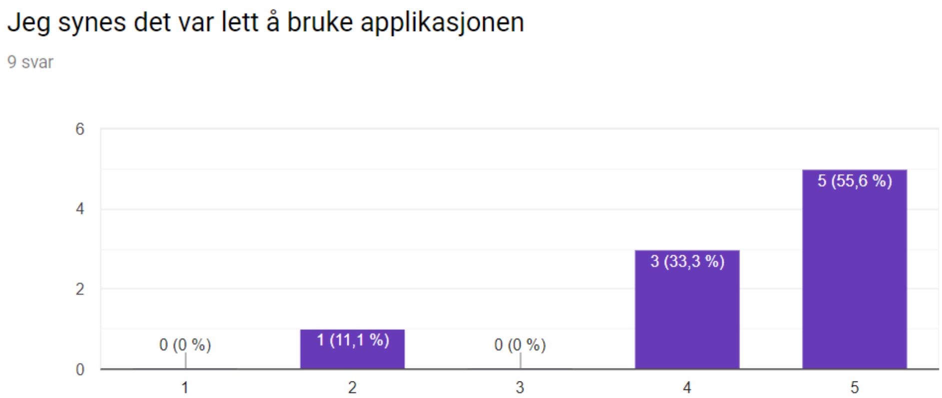

Figure 4.17: PE1

PE2: I thought it was easy to achieve what I wanted in the application The numbers are quite similar to the previous question (Figure 4.18). Out of the 9 participants all but two have answered the same to both PE1 and PE2, with both participants reducing their answer by one on the Likert scale. It would seem that it is slightly harder to achieve something in the application, than it was to use it. This is most likely due to the problems some participants encountered in progressing to the next scene.

Figure 4.18: PE2

PE3: I believe most people could learn how to use this application All participants believe that it would be achievable for most people to use the application (Figure 4.19).

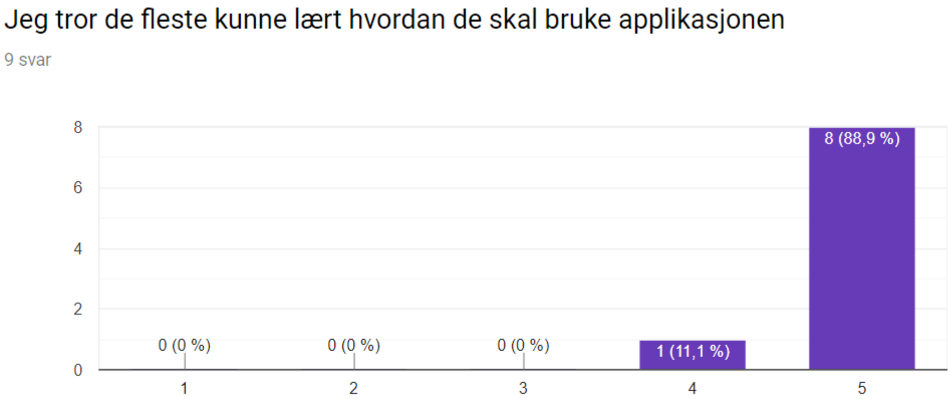

Figure 4.19: PE3

PE4: I thought it was cumbersome to use the application In this question the first schism in answer were seen (Figure 4.20). 5 of the participants strongly disagree with the statement, and 1 disagrees. However, there are 3 that agree with the statement. Two of the participants that agree with the statement rated themselves very low in programming competence, however the last one was neutral on the rating. Additionally other participants with low perceived competence did not find the application cumbersome to use. This seems to exclude perceived competence as a triggering factor. Another factor that was looked at was the previous answers to the perceived ease of use section. However, the results are much the same, i.e. no clear trend. The one participant who had rated the application with low perceived ease of use was among those that thought the application was cumbersome to use. But the other two participants either found the application very easy to use, strongly agreeing with all previous questions, or found it somewhat easy to use. Which makes it seem that the ease of use was not a triggering factor to their answers. Even when looking at the all the answers from the questionnaire there is no clear trend between the three participants. Two of three have a loose connection, in that they were generally rating some of the questions higher or lower than the average. However, they are usually not giving these ratings on the same questions, meaning their only connection is that they were generally less ”positive” towards the application than the average. An, unfortunate, possibility is that participants had different opinions on the definition of ”cumbersome”. This theory is supported by the fact that there seem to be no clear trend between the three. However, due to the small sample size it is difficult to draw a conclusion on this.

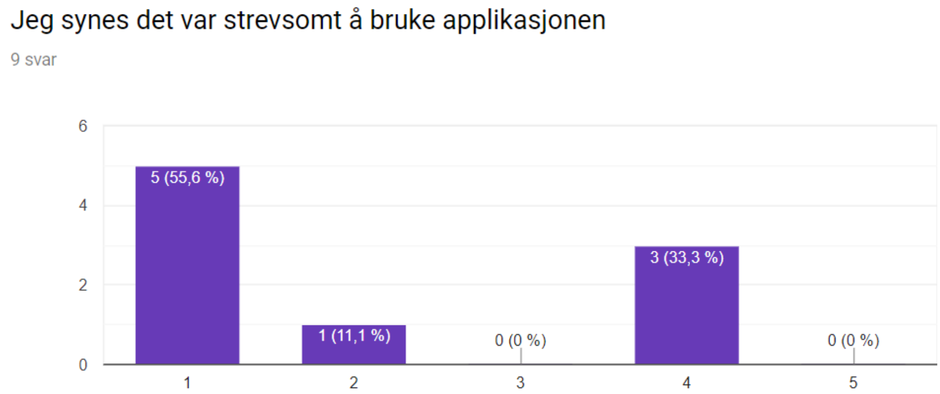

Figure 4.20: PE4

Course Quality

CQ1: I thought the information presented in the application was unclear Most participants disagreed with this statement, or were neutral (Figure 4.21). The agreeing participant was one who had rated their competence in programming very low, which might indicate that this was the cause. However, the other participants with low perceived competence in programming rated it higher, and one of the participants rating it neutral had a high perceived competence in programming. Which would indicate it is something other than perceived competence that is the triggering factor. However, as there is only one participant who had rated the statement this high it is difficult to find exactly what was the triggering factor.

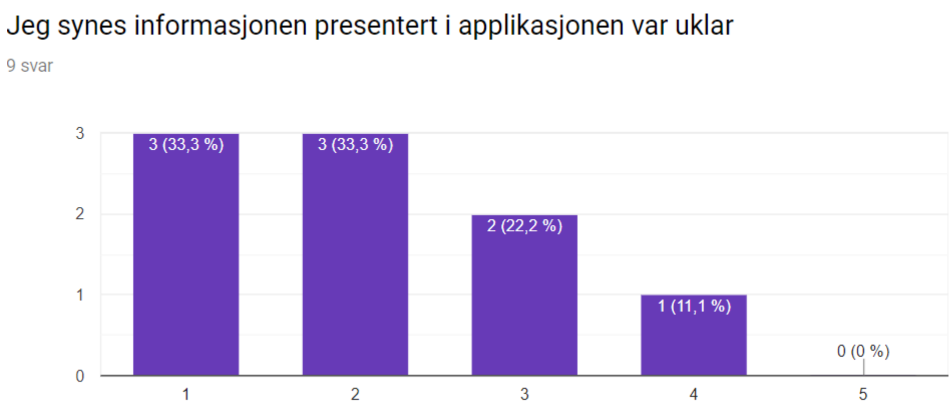

Figure 4.21: CQ1

CQ2: I thought the quality of the learning content was high No participants disagreed with this statement, meaning that the learning content was at the very least satisfactory (Figure 4.22).

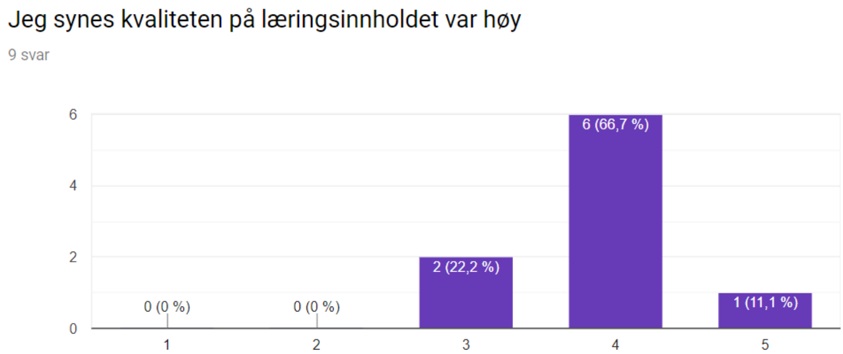

Figure 4.22: CQ2

CQ3: I thought the theme(programming) was a suitable topic for the application Most participants strongly agreed with this statement (Figure 4.23). Only three participants rated this lower than strongly agree. Interesting to note that the two of the three participants mentioned in PE4 are in this category.

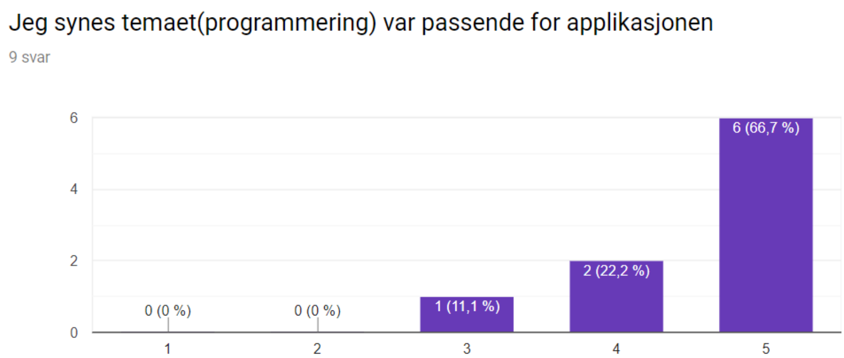

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Figure 4.23: CQ3

CQ4: I felt the visualization helped me understand the concepts presented in the application Interesting results on this question, as all participants rated it agree or higher, except for one (Figure 4.24). That participant had rated it strongly disagree. Intuitively one could assume that visualization would help with understanding a programming concept. Of course if there had been a trend of the visualization not helping other participants then this answer would not have been so surprising. But as this is the only participant to answer with a score lower than agree, it does seem odd indeed. In addition, this answer seems to contradict the other answers of the participant. This leads me to think that this might be a case of the participant either misunderstanding the question or checking the wrong box.

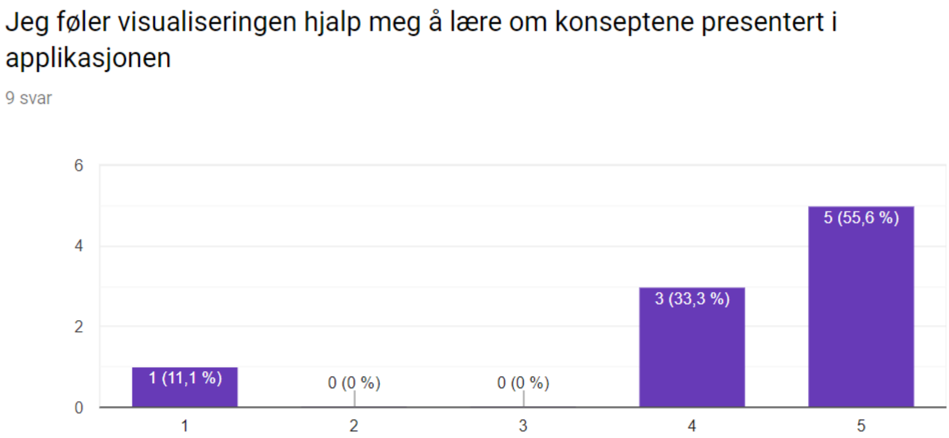

Figure 4.24: CQ4

4.3.3 Perceived Usefulness

PU1: I thought it was useful that the text in the application changed color As predicted participants found it useful that the text of the application would change color (Figure 4.25). However, due to the statement not being worded with modifying adverb, e.g. ”very”, it is difficult to say how effective it was based on the questionnaire alone.

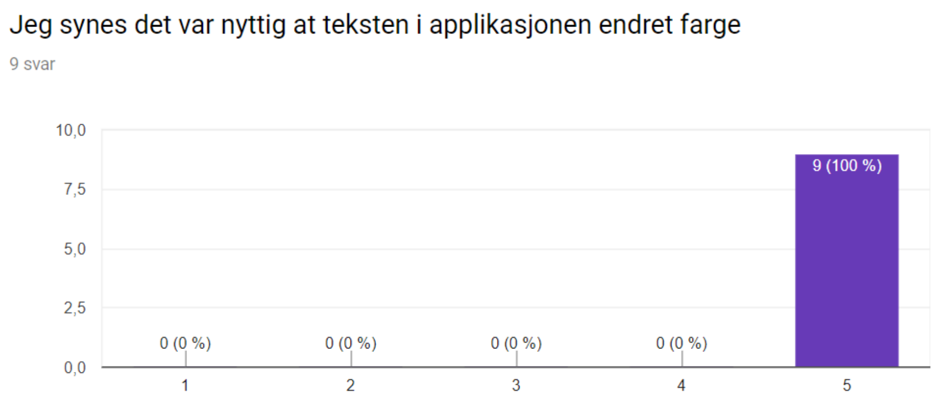

Figure 4.25: PU1

PU2: I thought it was useful that the elements of the game changed color Much the same results as from statement PU1, with only one participant rating it one point lower (Figure 4.26). And as with the previous question, the lack of modifying adverb does make it more difficult to ascertain to what degree it was useful for the participants.

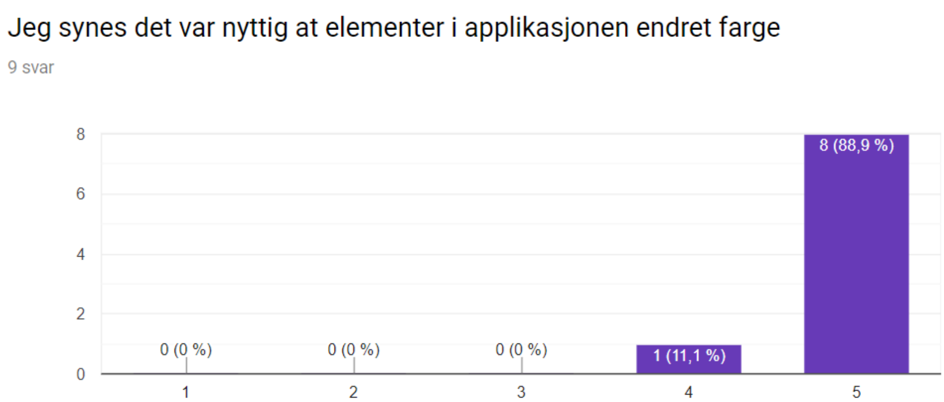

Figure 4.26: PU2

PU3: I thought it was useful that I was able to change the speed in the application All participants found it useful to be able to change the speed during demonstrations (Figure 4.27). Giving users control over how quickly they want to view the demonstration, allows them to find the right speed for them to learn. As one of the few areas where users could have agency in this application it seems important that users have some amount of control over how fast or slow they want to watch the demonstrations.

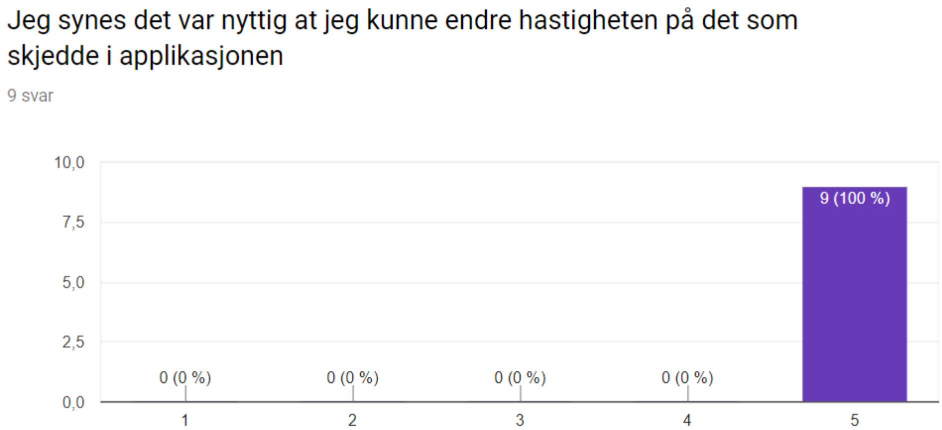

Figure 4.27: PU3

PU4: I thought the application was useful to understanding programming Most participants either agreed or strongly agreed with this statement, except one participant who rated it neutral (Figure 4.28). This was one of the participants with very low perceived competence in programming, and also the one that found the information unclear from CQ1 (*I thought the information presented in the application was unclear*). Considering their lack of experience, and that they found the information unclear, this could be a likely reason they found the application not particularly useful for understanding programming. Another finding was that experienced programmers also found the information presented in the application useful. In fact, of the 4 strongly agreeing participants, 3 perceived themselves as fairly competent in programming. When talking during the interviews one of the experienced programmers noted that programming had never been dynamically visualized to the participant before, and it gave that participant a new perspective on programming.

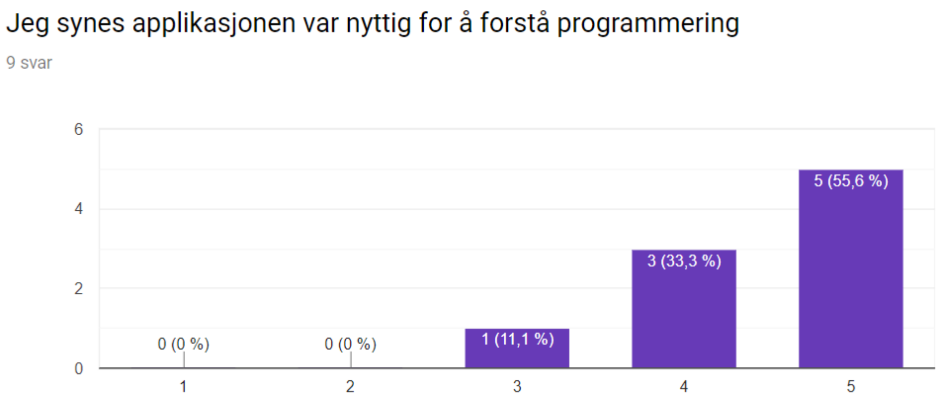

Figure 4.28: PU4

4.3.4 Perceived Satisfaction

PS1: I would like to learn more about programming in a similar application 6 participants agreed with this statement, with 3 participants being neutral (Figure 4.29). Perceived programming competency seems a natural cause for these neutral answers, as both very experienced programmers and inexperienced could conceivably be hesitant to continue learning programming in a similar interactionless application. The inexperienced user could find the task daunting, as they have no familiar concepts as a foundation to understand what is shown on screen. While the experienced programmer could find the application incapable of teaching them anything new. Of the three participants, there is a large difference in perceived programming competence. One participant considered himself very competent in programming, another as competent, and the last as inexperienced, but had attempted programming before. However, the answers from the other participants seems to indicate that perceived programming is not the cause for this. As there are no common themes on the statements that groups the inexperienced and experienced participants. However, when looking at the statements regarding computer anxiety, which will be detailed further in section 4.3.5, there is a commonality between two of the three participants mentioned. With the exception of the experienced programmer, two participants reported some levels of anxiety before trying the application. As computer anxiety is closely correlated to lower levels of satisfaction this could be the reason these two participants are more hesitant to continue learning programming in an interactionless application in VR.

Figure 4.29: PS1

PS2: I would like to learn more about a different topic in a similar application 8/9 participants answered the same on PS1 and PS2, with one notable exception (Figure 4.30). The experienced programmer mentioned in PS1 strongly agreed with this statement. Based on this it seems that the participant did indeed feel that the application was not as useful due to their high perceived competency in programming. In addition, the other two participants mentioned in PS1 had answered the same to both PS1 and PS2. Which further supports the theory that the participant with high perceived programming competency found the application less useful due to their programming experience.

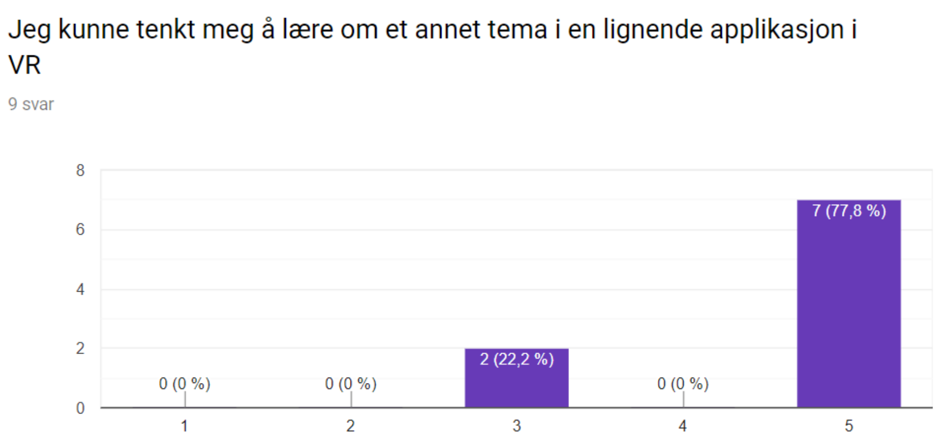

Figure 4.30: PS2

PS3: I believe the lack of interaction helped me focus Here the second schism of the evaluation appears, 4/9 participants agree, 4/9 disagree(with 1 strongly disagree) and 1/9 is neutral (Figure 4.31). Of the agreeing participants, the 2 participants who had never tried VR before appear. And the participant with the most experience in VR is among those that disagree with the statement. This indicates that experience is at least a factor for perceived satisfaction with interactionless. And as the inexperienced participants reported higher satisfaction, this seem to indicate that interactionless can be helpful for inexperienced users. These results will be further analyzed in section 4.4. However, due to the small sample size this is not conclusive.

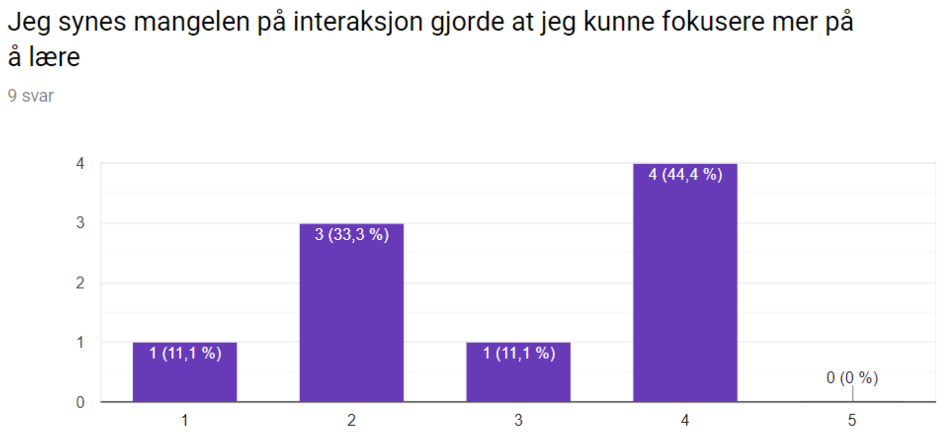

Figure 4.31: PS3

PS4: I feel I had too little control over what happened in the application 7/9 participants answered the opposite of what they answered to PS3 (Figure 4.32). However, two participants who disagreed with statement PS3 were only neutral to this statement. Of those two, one was the aforementioned experienced VR user, which further reinforces the idea that experience in VR influences the perceived satisfaction of interactionless VR. However, the major insight given by this statement is that it seems the biggest influence on the perceived satisfaction of interactionless VR, is whether a user feels they have *enough* control. It would seem that a lack of interaction is not a problem, and can even be conductive to learning, as long as users feel they are in control of the situation.

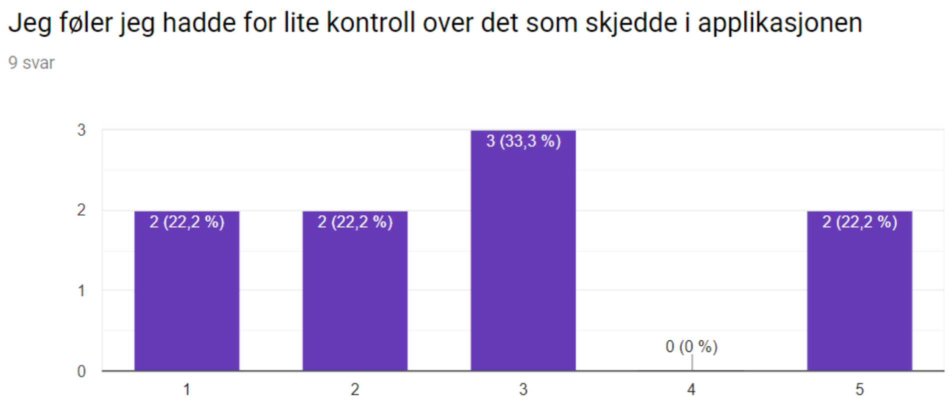

Figure 4.32: PS4

PS5: I greatly enjoyed having low amounts of control over what happened in the application The answers are pretty evenly distributed, 3/9 disagreed and 2/9 agreed, while the remaining 4/9 answered neutral to the statement (Figure 4.33). As would be expected the two participants who agreed with this statement had strongly disagreed with PS4. However, when looking at the participants who had disagreed with this statement the results are more interesting. Of the three who disagreed with this statement, the participants had all given different answers to PS4; one had strongly agreed to PS4, one was neutral, and the last had disagreed, being the only participant to answer the same to both PS4 and PS5. In the group of participants being neutral on the statement there is another notable discovery. While most participants who had answered neutral to PS5 followed a consistent trend of responding to statements PS3 and PS4 with neutral, or one point on the Likert scale lower or higher. One participant who stated neutral to PS5 had strongly disagreed with PS3 and strongly agreed to PS4. With these results it would seem that whether a user is satisfied with an interactionless VR experience can be found by looking at users attitude towards the lack of interaction. Whether a user will not be satisfied however, is dependant on other factors as well. As there are no clear trends in the questionnaire to explain why some users were not satisfied, and too few participants to say certainly, further research is required to find what aspects are correlated with a lower level of satisfaction.

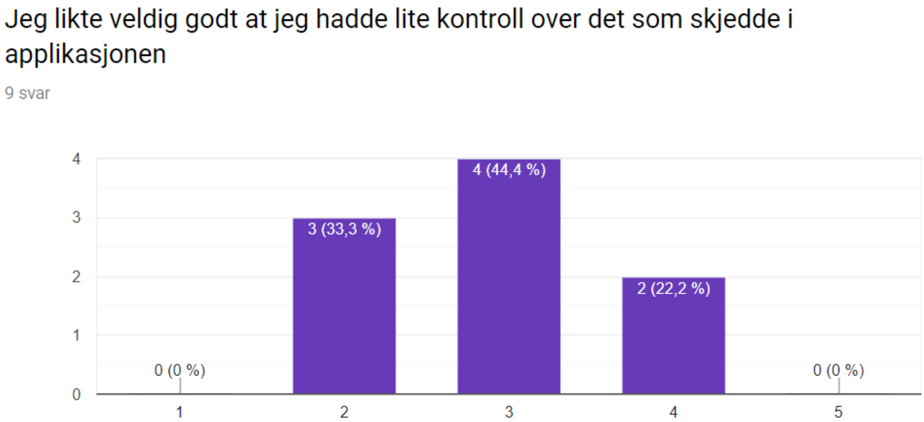

Figure 4.33: PS5

4.3.5 Computer Anxiety

CA1: I felt anxious before trying the application Most participants felt no anxiety before trying the application, but 3/9 did (Figure 4.34). However, no participant reported the same level of anxiety. Two of three participants with reported computer anxiety has been previously mentioned in PS1 and PS2 as having low perceived satisfaction of the application, and it would seem that in thread with the findings from Sun et al. computer anxiety can be an important factor in determining satisfaction. However, the last participant to report anxiety prior to trying the application do not show these same results, which means that computer anxiety does not necessarily correlate to lower perceived satisfaction.

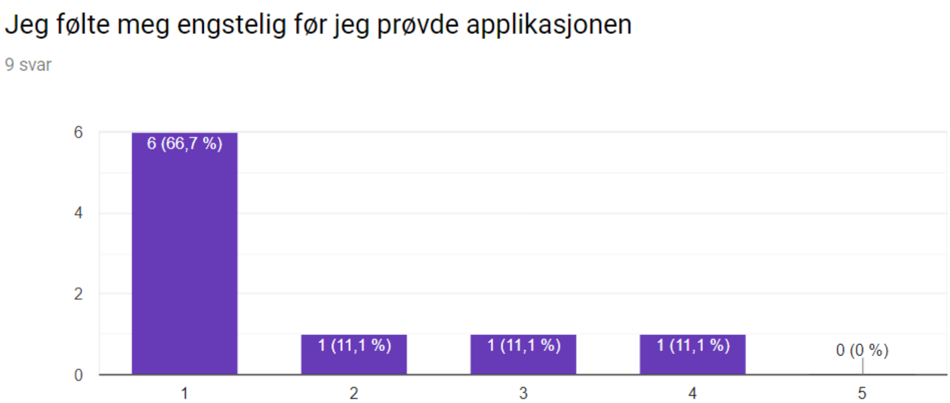

Figure 4.34: CA1

CA2: I was afraid I would look foolish while using VR Most participants fell on one of the extreme sides, 5/9 strong disagrees, 3/9 strong agrees and 1/9 disagree (Figure 4.35). Of note is that two of the participants who reported anxiety before trying the application were afraid of looking foolish. This could likely be the cause for why they felt anxious before trying the application.

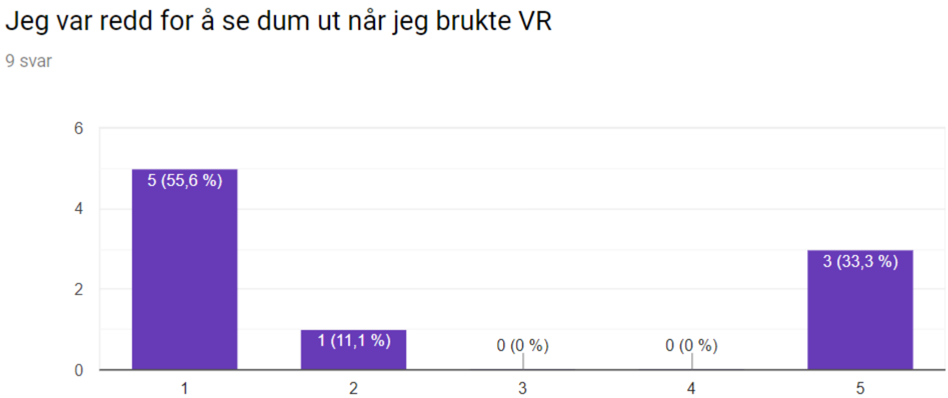

Figure 4.35: CA2

CA3: I was afraid of destroying the equipment while using the application 7/9 participants disagreed with this statement, while 2/9 agreed (Figure 4.36). Both of these participants strongly agreed with CA2, which shows there might be a correlation between statement CA2 and CA3.

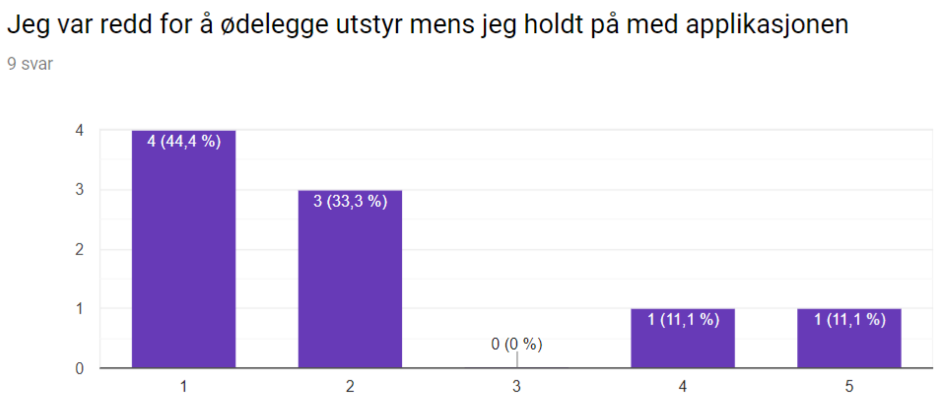

Figure 4.36: CA3

CA4: The application made me feel physical discomfort None of the participants experienced severe physical discomfort, however two reported a low level of discomfort (Figure 4.37). In both cases the participant felt disoriented while using the application.

Figure 4.37: CA4

4.4 Observation

From the observations two problems quickly became clear. One was a lack of feedback regarding when a participant had completed a scene. Many users would spend a long time in a scene anticipating that *something* would happen to let them know they were supposed to move on to the next scene. This was despite explicitly telling participants that they were free to move on to the next scene when they wanted. The other problem observed was that users would occasionally struggle with the controller command to move to the next scene. This is a developer oversight. Two buttons on the controller would have to be pressed to move to the next scene. unfortunately it was discovered too late that the button would have to be pressed close to simultaneously. This caused some problems for users, as they attempted to move to the next scene but was unable. The problem did not cause major problems for any participant as they were all able to move to the next scene within 5-10 seconds of attempting it. However, as noted in section 4.3.2 it might have affected the perceived ease of use.

Other than these problems a few trends were quickly observed. Those who were familiar with programming would usually increase the speed as soon as that option was able. Those with very little experience in programming would rather allow most demonstrations to run on the normal speed, sometimes increasing the speed when they had become more familiar with the concept. Some participants tried reducing the speed below the normal speed, but this was usually increased; it would seem that the standard speed is slow enough for most users. In addition, the duration of each participants stay in each scene varied greatly.

Interesting to note that those who stayed longest was those that had rather their competency in programming either very low, or very high. Those with low perceived competency stayed longer likely due to how unfamiliar they were with the concepts presented. And as such wanted to spend more time familiarizing themselves with these before moving on. However, those who had high perceived competency likely stayed longer due to their familiarity with the methods for testing users and gaining feedback.

4.5 Interview

During the interviews two major aspects of the application was discussed, immersion and agency. In addition, as the interviews were semi-structured other topics were frequently discussed. These included observations made during the test, follow-ups on comments from participants and discussions surrounding the design.

Immersion

All participants said they had felt immersed, one participant stating: "*From the moment I put on the [HMD] I felt that I was somewhere else*". This did not vary between individuals, as all stated that they were immersed. However, where they differed was in how immersed they felt. As the evaluation was conducted at the VR lab of IDI, it was common to have other non-participants present in the lab. This meant that participants could hear them moving around and talking, breaking immersion. In addition, there is a slight trend of participants with more experience in VR feeling less immersed in the application, than those who had never tried VR before. However, there were too few participants to say with any certainty whether this would true for a larger sample.

When discussing which parts of the application aided or hindered immersion a few factors repeatedly appeared with multiple participants. The largest contributor to immersion was the HMD. This is not directly related to the application, however as it is an important part of immersive-VR it must be mentioned in this section. Aside from the HMD, one of the biggest contributors to immersion was the fact the participants hands were visible and tracked inside the virtual environment(VE). Many users also commented on the design of the application as beneficial to immersion. Many participants felt it was similar to a classroom, immersing them in the task at hand. There were also some factors that participants felt reduced immersion. The biggest one being the lack of interaction. This supports previous research on interaction being an important factor in immersion. In addition, the aforementioned background noises that were present during some of the tests were reducing the immersion of affected participants.

Agency

All participants felt some degree of agency, that is they felt they were in control while using the application, with most participants stating they had felt a high sense of agency. As was the case with immersion, inexperienced VR users felt a higher degree of agency than those with more experience. And as with immersion, this difference is not pronounced enough to be called a trend. In addition, for some participants there is a noticeable difference between their answer in PS4 (*I feel I had too little control over what happened in the application*) and the answers given in this portion of the interview.

While discussing agency many participants stated that they had indeed felt mostly in control while using the application. All participants stated that being able to control the speed of the demonstration was the biggest contributor to a feeling of agency. And 4 out of the 9 participants stated that being able to start the demonstrations contributed slightly. These contributors cover two of the three actions users are able to take in the application. Being able to move to the next scene was not mentioned by any participants as increasing a feeling of agency. When discussing what aspects had reduced the feeling of agency participants felt, only two participants felt an aspect had reduced agency. For both it was the same, and that was the linear progression in the application. As they could not control what demonstration to view next they had felt less agency.

With these results it seems that despite participants being unable to interact with elements in the application, the few tools they have at their disposal to control what happens is enough to give users a sense of agency.

4.5.1 Other Findings

Among the other findings there are two that are notable. The first being a question all participants were asked: ”Do you think you would have enjoyed the application more, if you had to complete a task to move to the next scene?”. 5 participants disagreed with the statement, 2 were neutral, and 2 agreed. The disagreeing participants were mostly those inexperienced with programming, but not exclusively. One of the participants with the highest level of perceived competency in programming felt that it was not necessary to include tasks. However, with the follow-up question: ”Would you have liked to eventually be introduced to tasks?”, all participants agreed. This indicates that while an interaction-less application can be useful, eventually most, if not all, users would like to interact with the application. The next finding was something that was brought up by the first participant who took part in the evaluation: the application seemed perfectly suited to novices in either programming or VR. This had not been considered before this point, and since it was discovered at the beginning of testing this was included for future tests. All of the participants could be rated as inexperienced in VR, as none of the participants had used VR more than 3 times(the participant who had tried VR 4-8 times had been the first participant to test the application). The results were unanimously positive. Both participants with no previous VR experience, and participants who had never attempted programming before found the application well suited to this purpose. The most common reason stated, was that the application had no fail state. This lead to a low stress environment were users could take the time they felt they needed before proceeding. In addition, most users felt the relaxed nature of the application was a good introduction to VR. As found in CA4, very few participants felt any physical discomfort from the application, and those that did had mild symptoms.

4.6 Limitations

The post-questionnaire should have been worded more strongly, adding modifying adverbs to most of the statements that lacked one, such as changing PU1 to: "I thought it was *very* useful that the text in the application changed color". In addition, the questionnaire was only validated by the supervisor, and could have benefitted from a more extensive survey, for instance a pilot test. The evaluation would also have benefitted from more participants, in order to get more quantitative data. In addition, participants were given the definition of immersion and agency during the interview, and this could have affected the answers given. However, this would be very difficult to overcome, as participants must understand the definition in order to answer questions surrounding the concept. Lastly, as previously mentioned the lab had other non-participants present, which caused background noises. The test should have been conducted in a room with only the participant and observer present, but this was very difficult to achieve, due to the computer requirements of modern VR equipment.

Chapter 5

Discussion

5.1 Research Questions

The main research question was: **What is the potential of interactionless VR in education?**

In order to answer this question three sub-questions were asked, which will be discussed first.

5.1.1 RQ 1. How can an interactionless application in VR be implemented?

The application was created with the blackboard as the focal point for users. This proved to be very effective for the most part. Users did indeed spend the majority of their time looking at the blackboard observing the code as it executed, and the participants found it intuitive that this is where they were supposed to look. However, they would occasionally look away to observe when a number cube would be affected by the system. It was during these brief moments when users would not be looking at the blackboard a problem would occur. The feedback mechanics used to indicate that a user could move to the next scene were often activated precisely when participants were looking at the number cubes, and not the blackboard, where the feedback would be displayed. There are two easy solutions to this problem. The first being to move the cubes to be more easily perceived while looking at the blackboard. For instance in the variable scene of the application; the number cubes were placed close to the participants location, and this made it difficult to view both the cubes and the blackboard simultaneously. As such participants often missed the text flashing green, indicating that the scene was completed. However, a simpler solution would be to implement a different feedback mechanic entirely. For instance a light that is red while users have yet to complete a scene, and green when they have completed it. Either way a proper feedback mechanic is critical to the success of an interactionless VR application.

The design was received positively by all users. Participants found it simple and clean, but most importantly participants stated that it helped immensely in knowing where to look. The only 3D-objects in each scene that are not white, are used by the system to visualize what occurs during the execution of the code. As previously mentioned, guiding the users' gaze is a critical component of VR, and I would argue especially interactionless. As users are not the ones to cause changes to occur, it is necessary to guide the users gaze towards the vital actions that occur. I would also argue that a design that is intentionally very simple is of help to users. This reduces clutter, and further aids in guiding the users' gaze.

Most participants from the evaluation stated that seeing their hands in the VE helped with their feeling of immersion. As many VR applications are attempting to imitate reality, giving users a way to translate their real-life actions to the VE seems important, despite those actions not necessarily achieving anything in particular. Giving users an avatar would be an effective way to achieve this. In addition, by allowing the participants to view their hands, the controllers could also be made visible. This could help in case a user forgot where a button is located on the controller.

From what was learned from this thesis it would seem that guiding the users' gaze is the most important aspect of implementing an interactionless VR application for use in education. The simple design proved effective, and I would argue that in an application where users are not interacting with elements in-game a simple design should be aimed for. Especially since it enhanced how effective the application was able to guide the users' gaze. Allowing users to view their hands do not seem to be critical, however it did increase immersion.

5.1.2 RQ 2. How do users experience using an interactionless application in VR?

Immersion The biggest contributor to the immersion was the HMD, it would seem that by just covering the users FoV immersion can be achieved. However, it was also noted that most participants did not feel a high immersion simply by the HMD. Another big contributor was the fact that participants were able to see their hands in the virtual environment (VE). This allowed for their real life actions to be represented in the VE and gave the participants a feeling of being present in the scene. Another aspect that participants felt increased immersion was the design of the scenes, many could relate to the design and it was commonly associated with a classroom. However, there were also factors that negatively impacted the immersion participants felt. Of the two mentioned in section 4.5 only one was a result of the application, and that was the lack of interaction. This does confirm the findings of previous research, that interaction is an important factor of immersion.

All participants felt a high degree of immersion while using the application. This shows that despite the application being interactionless, immersion is still achievable. As mentioned the biggest contributor to this was the HMD, and the second biggest was the user being able to see their hands in the VE. As both contributors are handled by the equipment, immersion is achieved to a large degree by the equipment itself. However to achieve maximum immersion, additional factors that enhance immersion should be considered. A notable exclusion from this application is the use of sound. It was mentioned that some participants felt that the background noises during the evaluation broke their immersion. By using sound it would be possible to block out much of this background noise. It would also seem that designing scenes to be realistic can enhance immersion, as it gives users a real-life equivalent to compare the scene to.

Agency Another important aspect of the user experience was to what degree participants felt that they were in control while using the application. Across the participants two reasons were mentioned as giving a sense of agency. The biggest influence was being able to control the speed of the application, and for some participants being able to start the demonstrations when they wanted was reported as giving a sense of agency. Notably excluded is moving to the next scene, as no participant mentioned this as increasing agency. One could naively assume this means that giving the user control over when to end the scene is not necessary for agency. However, it is highly likely that is a scenario where the users don't notice it while it is present, but they will notice if it is gone.

As previously mentioned in the results chapter, there were some discrepancy in two of the participants answers regarding PS4(*I feel I had too little control over what happened in the application*) and their answers during the interview. Specifically the participants who had strongly agreed on PS4, but during the interview claimed that they had indeed felt a high sense of agency. Both participants reported the ability to start the demonstrations, and change the speed as the cause for their sense of agency. There are some probable causes for this. The first, and perhaps most obvious, is that they had interpreted PS4 in a way that does not reject a sense of agency. For instance, being unable to control what appeared on the blackboard, but still having a sense of agency due to being able to change how fast it would execute. Another possibility is that participants were influenced by the interview. Before discussing agency, participants were given a brief definition of the concept and the actions participants had available were quickly discussed. It is possible that being reminded of the controls affected how the participant viewed the test in hindsight, causing the discrepancy between PS4 and the interview.

As all participants felt a sense of agency, and some participants said they had felt a high degree of agency, it would seem that an interactionless application in VR is very much capable of providing a sense of agency. The most important factor was controlling the speed. As this is related to how the information is presented to the user, this seems to be an aspect of interactionless VR where users should feel a great degree of control. Being able to start the demonstrations were viewed as being less important, however if one were to implement an interactionless application one should be wary of not letting users being control of this as well. This is mainly due to the fact that allowing users to start the demonstration when they want greatly increases the odds that users are gazing towards what the developer wants them to. The only factor found during the evaluation to affect agency negatively was the inability to choose which scene to enter after finishing the current scene. Allowing users to choose which scene after finishing a demonstration could easily be achieved without breaking the definition of interactionless, as used in this thesis. For instance when a user wants to leave a scene all available scenes could be displayed and users could choose from there.

This research question would have benefitted from having more participants, and especially participants with no previous experience in VR.

5.1.3 RQ 3. What aspects of interactionless VR affect the perceived satisfaction of learners?

In this thesis 3 aspects of interactionless VR were planned to be evaluated: guiding the users' gaze, the lack of interaction and the ease of using the application. However, as this was an exploratory study it was important to be vigilant in case any new interesting aspects were discovered. The accessibility, defined in this thesis as the ability to use this application for users with no previous experience in VR, was the only new aspect to be found during the thesis. In order to explore these aspects they would have to be related to perceived satisfaction. As previously mentioned perceived satisfaction is closely connected to other factors, and aspects of the application were mapped to these factors in the following manner: guiding the users' gaze to perceived usefulness, lack of interaction to perceived satisfaction, and ease of use was related to perceived ease of use. Accessibility stands out as the only aspect that encompasses several factors of perceived satisfaction, however as this is the accessibility of users with no previous VR experience computer anxiety is main factor that will be explored in this chapter.

Perceived usefulness and perceived ease of use were of high importance to this research question. This is due to the fact that both factors are influenced by the implementation, making them essential to further the understanding of interactionless VR. Course quality and computer anxiety were secondary. Course quality is dependant on the learning content being of high quality, and computer anxiety is a general apprehension towards, in this instance, VR. This means that these are not affected by the implementation of the application itself. However, as course quality was found to be the factor that impacted perceived satisfaction the highest by Sun et al. it was vital to gather data on it. Since if participants viewed the course quality as being low, this could affect how they viewed the application in its entirety. In the same vein is computer anxiety. The application has no aspects that are implemented with the purpose of reducing computer anxiety. However, as it negatively affects satisfaction it was necessary to gather data on computer anxiety to gauge whether this had affected the perceived satisfaction.

Guiding the users gaze proved to be both helpful and effective at directing users to where the system was currently operating. Participants stated that it was for the most part easy to keep track of what was happening, why, and what would be the next action taken by the system. The measures taken to guide the users' gaze was to keep the design of the scenes simple, and change the color of text and cubes. Both factors were mentioned as helping participants know where to look. However, as previously mentioned there was a problem with feedback mechanics and guiding the users' gaze. Participants would follow where the system guided their gaze, and would miss the feedback. This would however have been simple to correct, if it had been discovered before the evaluation began. Despite these problems, as users are not interacting with elements of the application, guiding the users gaze appears to greatly correlate with perceived usefulness.

Most participants found the application easy to use. This was not surprising as users have essentially three actions to take while using the application. However, some participants encountered problems when they were trying to move to the next scene, where both buttons on the controller would have to be pressed almost simultaneously. This too would have been easy to adjust had the problem been identified before evaluation. And this is likely the reason that some participants gave the answers they did on the questionnaire regarding ease of use. However, from the answers given to the rest of the questionnaire it does not appear that perceived ease of use had a significant impact on the perceived satisfaction. The two participants who had rated both PS1 (*I would like to learn more about programming in a similar application*) and PS2 (*I would like to learn about a different topic in a similar application*) as neutral, had different answers to the statements on perceived ease of use. This seems to indicate that perceived ease of use did not affect the perceived satisfaction of this application in a significant capacity. However, when looking at answers to the lack of interaction the results are different, which will be discussed in the following paragraph.

The lack of interaction in the application was received differently by the participants, some were satisfied, while others were not. Notably the two participants who had never tried VR before reported being largely satisfied with the application and its lack of interaction. However, there were 3 participants who were not particularly satisfied with the lack of interaction. One of them was the participant with the most VR experience, which seem to indicate that an interactionless VR application is not suited for experienced users, though the sample size of one is much too small to give a conclusive answer. The other two participants who were not satisfied had rated the ease of use of the application lower than all the other participants. Since the usage pattern of the application is entirely determined by it being interactionless, it would be natural to assume that participants who had difficulties using the application were less satisfied with it being interactionless. However, it is possible that if the aforementioned problems with feedback and moving to the next scene were fixed, that it would have a major positive impact on the perceived ease of use. One interesting occurrence is that none of the participants had answered PS5 (*I greatly enjoyed having low amounts of control over what happened in the application*) with either strong agree or strong disagree. Most participants seem to simply be content with the application being interactionless. It would seem that interactionless VR have no inherent benefit that would make it generally better than regular interactive VR. However as has been mentioned, it does show some potential in filling certain niches. The most prominent being that of introducing beginners to VR, especially when considering factors such as computer anxiety.

While it was originally planned to have computer anxiety act as a secondary measure of perceived satisfaction, due to the discovered potential of the application as an introduction to VR it was prioritized higher. The results from the questionnaire were quite interesting with most participants reporting no significant computer anxiety, however only two participants had strongly disagreed with all the statements regarding computer anxiety. Of the remaining seven, four would only report computer anxiety on one statement. The remaining three however, reported what could be considered significant computer anxiety. The only statement that these participants had answered the same was CA2 (*I was afraid I would look foolish while using VR*), where they had all strongly agreed. On the other statements these participants did not answer the same, whereas one participant reported significant anxiety before the evaluation, the other two did not. And these same two who did not feel anxiety before the evaluation were afraid of damaging the equipment, while the participant who did feel anxiety was not afraid of damaging the equipment. This shows that participants experienced computer anxiety differently, and to different degrees. When interviewing participants it was revealed that the participants who had felt any amount of computer anxiety before the evaluation, had quickly had their fears diminish when they understood how the application operated. This further indicates that interactionless VR is well suited for inexperienced VR users, however it also shows that users who might struggle with computer anxiety could find an application like this beneficial.

All the aspects that were evaluated proved to affect the perceived satisfaction. Guiding the users' gaze seems to be the most important aspect of an interactionless VR application to increase the perceived satisfaction. As users are not in control of what the system does and where, I argue that this is a vital aspect of interactionless VR. Ease of use was proved to affect satisfaction positively when participants found it easy, and negatively when participants found it hard. This was not surprising, but it does further emphasize that it is important that the actions users take are easy to comprehend and use. The lack of interaction in itself was more difficult to explore thoroughly, as it seems that participants had different opinions on it, based on different factors. A few factors have been discussed as possibilities for the various participants' statements, but due to the limited sample size no conclusion can be drawn on this point yet, further research is required. Lastly, the application as a tool for users with no previous VR experience. This is where I argue that interactionless would be most useful. No participants reported any significant forms of VR sickness, with only two participants stating they had were disoriented after testing the application. The application was a low stress environment, where participants could take their time and the system would pose no intentional obstacles for the participant to overcome. However, to be able to conclusively say whether interactionless VR can be a useful tool for users with no previous VR experience further research is needed.

5.1.4 Main Research Question

With all of this in mind, to answer the main research question: what is the potential of interactionless VR in education?

The main potential of interactionless VR appears to be as an introduction to VR for users with no or little previous experience in VR. Such applications could easily be used in variety of situations where the users experience with VR is low or unknown, for instance in classrooms. This would allow for these users to be eased into virtual reality, with little worry of making errors or breaking the equipment. In addition, as very few participants in the evaluation felt physical discomfort this is another area where interactionless VR could aid inexperienced VR users. However, when users become more familiar with VR the lack of interaction could easily become a negative, as mentioned all the participants in the evaluation would like to eventually interact with the system. To solve this problem I would suggest that developers create applications that contain both interaction and interactionless. This way one could ease beginners into VR, while also providing an interesting experience later on, more on this in future research 6.1.

However, besides this there are not any potential uses where interactionless stands out as being more suited than regular VR, based on this research alone. There are still many aspects of interactionless VR that could be researched which could open up new avenues for uses of interactionless VR.

5.2 Reflection

This thesis has taught me a lot about the scientific process and how to view the data generated. There were many obstacles to overcome: how to gather data, how to analyze that data, finding the right literature for the thesis, etc. It has been a valuable experience, and one that I hope to be able to make use of later in life.

What I felt was the biggest obstacle was narrowing down the scope of the thesis and finding satisfactory research questions. The majority of the first semester was spent on this, and even that was not sufficient as the thesis changed focus halfway through the second semester, and the research questions were not finalized until early May. However, having gone through the process of refining and narrowing the thesis, I have learned a lot about this process. I have become far more familiar with finding and researching suitable topics.

A consequence of finding the defined scope of the thesis this late, was that the implementation and subsequent evaluation was not optimal. For the implementation I would have liked to gather much more input on the design, functionality and usability before starting the evaluation. This would allow for the small inconveniences that occurred during the evaluation to be eliminated, or at least mitigated. In addition, findings such as the application being suited for users with no previous experience in VR could be accounted for, and explored much more thoroughly.

The questionnaire would have benefitted greatly from verifying it, for instance with a pilot test. With this I could have discovered if any questions were confusing to participants, and how they were interpreted. There was a problem with the wording on some questions (in particular the ones regarding perceived usefulness and their lack of a modifying adverb), and running the questionnaire through a pilot test would likely have improved many of the questions that were deemed unsatisfactory. In addition, due to the time constraints I could not spend as much time analyzing the data as I would prefer.

Chapter 6

Conclusion and Future Work

This thesis sought to explore what potential interactionless VR had in education. A prototype of an interactionless VR application teaching programming was created and a user evaluation was conducted in order to explore the user experience and perceived satisfaction of participants who used the application. The greatest asset exhibited by interactionless VR seems to be as an introduction to VR for users with little to no previous experience in VR. This thesis has shown that both immersion and agency can be produced by an interactionless VR application. To create such an application a few key factors were explored. Guiding the users' gaze stands out as the most important; as users are not interacting with the elements of the application they should have directions on where to look. However, while interactionless VR seems to hold potential in introducing inexperienced users to VR, it does not seem to have any other benefits that would make it more suited for education than interactive VR.

6.1 Future Work

This chapter will detail some of the potential approaches for future researchers who wish to explore interactionless VR.

One approach for future researchers would be to create an application that combines both interaction and interactionless. One possibility to achieve this would be similar to Rudder's[26] approach, where the user is first presented the concept visually with no input from users, and then have them solve a task or use the information in other ways, and when they finish they are again introduced to a new concept in interactionless. A similar approach would be to have the first part of the application take place in an interactionless setting. While the later stages requires interaction from users. Of these two, I argue that Rudder's approach is best. There are two main reasons for this. The first being that using the knowledge while it is still fresh in memory is more effective. The other being that intertwining interaction and interactionless scenes would keep the application from becoming monotonous.

Another approach to further research interactionless VR specifically, would be as an introduction to VR for those who are inexperienced in VR. As mentioned this seems to be the most promising area where interactionless VR could perform better than interactive VR. The application caused very few symptoms of physical discomfort, and those who did experience it, felt only mild symptoms. As a bad experience in VR can be detrimental to later usage, it could prove very beneficial to introduce users with an interactionless application first. One could research if beginning with an interactionless VR application reduces VR sickness when using other applications later. In the same vein, one could explore the uses of an interactionless VR application in novices to any given topic. As there were no fail-states in this application many participants commented on how stress-free the test had been. This could allow for users being able to explore a topic with no previous experience without being afraid of the system punishing them for their lack of knowledge.

Immersion in interactionless VR applications is also a possible field for further study. This thesis only explored whether an interactionless application could achieve immersion. The next step would be to find what factors are critical in order to achieve immersion in an interactionless VR application.

Feedback mechanics in interactionless VR should also be researched if the field is to be explored further. As users are not interacting with elements in the game, developers will need to direct users to the correct information. One of the themes of the application implemented for the thesis was that users should be allowed to progress when they wanted, and not when the system made them. However, this freedom necessitated feedback mechanics that did not obstruct the progression of users. A few different mechanics were explored, but none had proved very effective in conveying to a user both that they were allowed to advance, but that it wasn't necessary if the user wanted to spend more time in the scene.

One aspect that has been previously mentioned, is the fact that it would likely be much easier to implement several variation of the same concept in interactionless VR compared to regular VR. This aspect was however not thoroughly explored during this thesis, as I did not create an additional application to compare the development time. As such it could be researched to what degree interactionless reduces development cost compared to interactive VR.

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Appendices

Appendix A

Appendix

Pseudonym	Blå Drage	Blå Fugl	Grønt teppe	Brun Hest	Bråkete Dovendyr	Grå Hund	Blå Hest	Dovent dovendyr	Sort Maurspiser
Jeg synes det var lett å bruke applikasjonen	5	5	2	5	4	4	5	4	5
Jeg synes det var lett å oppnå det jeg ønsket i applikasjonen	5	4	2	5	3	4	5	4	5
Jeg tror de fleste kunne lært hvordan de skal bruke applikasjonen	5	5	5	5	5	5	4	5	5
Jeg synes det var strevsomt å bruke applikasjonen	1	1	4	4	4	1	2	1	1
Jeg synes informasjonen presentert i applikasjonen var uklar	1	1	4	2	3	2	2	3	1
Jeg synes kvaliteten på læringsinnholdet var høy	4	4	3	4	3	4	5	4	4
Jeg synes temaet(programmering) var passende for applikasjonen	4	5	3	5	4	5	5	5	5
Jeg føler visualiseringen hjalp meg å lære om konseptene presentert i applikasjonen	5	5	5	5	4	5	1	4	4
Jeg synes det var nyttig at teksten i applikasjonen endret farge	5	5	5	5	5	5	5	5	5
Jeg synes det var nyttig at elementer i applikasjonen endret farge	5	5	5	5	5	5	5	4	5
Jeg synes det var nyttig at jeg kunne endre hastigheten på det som skjedde i applikasjonen	5	5	5	5	5	5	5	5	5
Jeg synes applikasjonen var nyttig for å programmering	5	5	3	5	4	5	5	4	4
Jeg kunne tenkt meg å lære mer om programmering i en lignende applikasjon	5	3	5	5	3	5	5	3	4
Jeg kunne tenkt meg å lære om et annet tema i en lignende applikasjon i VR	5	3	5	5	3	5	5	5	5
Jeg synes mangelen på interaksjon gjorde at jeg kunne fokusere mer på å lære	2	4	1	4	2	2	4	3	4
Jeg føler jeg hadde for lite kontroll over det som skjedde i applikasjonen	3	1	5	2	5	3	1	3	2
Jeg likte veldig godt at jeg hadde lite kontroll over det som skjedde i applikasjonen	2	4	3	2	2	3	4	3	3
Jeg følte meg engstelig før jeg prøvde applikasjonen	1	2	1	1	4	1	3	1	1
Jeg var redd for å se dum ut når jeg brukte VR	1	5	5	1	5	1	1	2	1
Jeg var redd for å ødelegge utstyr mens jeg holdt på med applikasjonen	2	4	5	1	2	1	1	1	2
Applikasjonen fikk meg til å føle fysisk ubehag	1	1	2	1	1	1	1	1	2
Hvis du følte fysisk ubehag, hva følte du?	Ingen	Ingen	Desorientert		Ingen		Ingen	Ingen	Desorientert

Appendix B

Requirements

ID:	FR1
Title:	System should guide the users gaze
Desc:	The system should use color and color change to direct the users gaze to where they should be looking.
Status:	Implemented

ID:	FR2
Title:	User must be able to view both the executing code and the corresponding actions
Desc:	While the user is engaged with a visualization they must be able to simultaneously view both the executing code and the actions that take place as a result of the code.
Status	Partially Implemented

ID:	FR3
Title:	The system should be accessible for players of different levels of VR experience
Desc:	The application should be usable by both users that are experienced in VR and users that have little to no experience with VR.
Status	Implemented

ID:	FR4
Title:	Users shall be able to start the application without interacting with in-game elements.
Desc:	When a user wants to start the execution of code this shall be done by pressing a button on the controller
Status	Implemented

ID:	FR5
Title:	System must change the color of executing code
Desc:	When the system is visualizing a programming structure, the color of the text must change according to how far the code has executed.
Status:	Implemented

ID:	FR6
Title:	A demonstration should have at least two different examples that users can view
Desc:	When viewing a demonstration of a programming concept it should be at least two different examples that users can view.
Status	Not implemented

ID:	FR7
Title:	User should be able to change the time-interval between actions in a demonstration
Desc:	When the system is going through a demonstration the time between actions might be too quick or too slow for some users, as such they should be able to change how long it takes for the system to move to the next step in the demonstration.
Status:	Implemented

ID:	FR8
Title:	Users must be able to change the speed without interacting with in-game elements
Desc:	When a user wishes to change the speed of the application this must be done with the controllers.
Status:	Implemented