

Erlend Gjelsvik and Simon Hagen Strand

Creating a Virtual Reality Application with Game Elements for Teaching Geometry

Master's thesis in Informatics

Supervisor: Monica Divitini and Ekaterina Prasolova-Førland

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Abstract

This thesis has explored the potential benefits a Virtual Reality(VR) application with game elements might have for first-year high-school students learning geometry. First-year High-school students score an average of 2.4 on the exam for mathematics in 2017, and 3.0 for second-year students. This shows great potential for improvement. VR is effective for spatial visualization and interaction, which makes it a great tool for teaching geometry. The "design and creation" research method has been used for this project, which resulted in a VR learning application for geometry. The application is based on constructivism and pedagogical principles for learning geometry. Researchers do generally agree that constructivism is best suited for learning and teaching in VR. The application was evaluated in two phases. This was done by testing the application with high-school students, math teachers, an expert in didactics of mathematics and an expert in serious games. The findings suggest that a VR-application with game elements has the potential to help some students further their understanding of geometry through interactive figures and exploration. The results also indicate that VR can help increase the motivation and focus of students and that the use of game elements, such as environment, story, and puzzles, can further increase motivation. This study does also suggests important requirements to follow when creating a VR-application as an aid in teaching geometry. Further work should look more thoroughly into the learning outcome of the use of VR for learning geometry.

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1 Introduction

This chapter will explain our motivation for conducting the research and say in which context the research is being conducted. Further, the problem will be defined, and the research questions presented, before finishing with an outline for the report.

1.1 Motivation

By looking at the statistics from high schools in Norway, several students are having problems with mathematics. In 2017 the average overall achievement grades for P1 were 3,4 and 3,6 for P2, while the average grades on the exam were 2,4 for P1 and 3,0 for P2[2]. According to UD (Utdanningsdirektoratet), the Norwegian Directorate of education, 81% of the students get a worse grade on the exam than they do on the overall achievement grade. This shows that there is potential for improvement.

Geometry is one of the longest established branches of mathematics and is used in a wide range of applications. Many visual proofs are based on geometry, which makes it a powerful tool and one of the most essential branches in mathematics. Spatial reasoning and visualization plays an essential role in geometry and geometry education but is also essential in other branches of mathematics and mathematics education [3]. Clements and Battista[4] defines spatial reasoning as “The set of cognitive processes by which mental representation for spatial objects, relationship, and transformations are constructed and manipulated.” By this definition, it would seem that Virtual Reality(VR) will be a powerful tool to achieve better spatial reasoning because of it’s effectiveness for spatial visualization and interaction[5].

Virtual Reality is a technology that was first experimented on in the early 1960s[6]. It is not until recent years that significant progress has been made to the technology, which has given VR a vast increase in popularity[6]. VR has been driven forward by the gaming industry but has many other potential uses like visualization and education. Previous research has been done in the area of VR for education[6], and there have been many attempts at using VR in education.

From the review on related works, we found that there was little research done on VR for geometry, but those found are described in Section 2.4.1. The immersive capabilities of VR could aid in learning geometry and also reduce negative emotions towards maths. It would be interesting to check if the use of the game elements: story, aesthetics, and theme can improve the motivation of students.

1.2 Context

This project was started in August 2018 and ended in June 2019. The report is written as a master thesis at the Norwegian University of Science and Technology (NTNU). We are two master students of Informatics at the department of computer science (IDI), specializing in Interaction Design, Game, and Learning Technology. The application was developed using the equipment available at the IMTEL VR-Lab at Dragvoll.

1.3 Problem definition

VR has been shown to be a powerful tool in certain fields of training and education. In this thesis, we want to address the use of VR technology as an aid in the teaching of geometry. First-year high school students were chosen as the target audience because of their potential for improvement in mathematics. The topic of geometry was focused on because of its visual nature, and its importance in mathematics. Our goal has been to give some insights into the challenges that must be solved to make VR technology beneficial to the teaching situation.

1.4 Research questions

These are the research questions for this thesis. They consist of two types of questions, process related questions, and purpose related questions. RQ1, RQ2, and RQ3 are related to the process of creating the application, while RQ4 and RQ5 are related to the purpose of the application.

- **Main Question:** How can a VR-application with game elements help students learn geometry?
- **RQ1:** What are reasons for the use of VR in teaching geometry?
- **RQ2:** What are the requirements for such an application?
- **RQ3:** What are the problems with developing such an application?
- **RQ4:** How can the VR-application improve understanding of geometry?
- **RQ5:** How can the VR-application help motivate students learning geometry?

1.5 Report outline

This section will describe the contents for the rest of the report.

- Chapter 2: This chapter will present the background theories and knowledge used in this project as well as presenting related works.
- Chapter 3: Here, the research methods used will be presented together with software and hardware used for development and testing.
- Chapter 4 and 5: These chapters describe the process of development in two phases. It will go into the early stages of exploration, the making of requirements, the development, and the evaluation of the application.
- Chapter 6: This chapter will discuss the results and their meaning as well as the limitation. Further, it will present the answers to the research questions, list the contributions of this study, and suggest future work.

2 Background and Related work

This chapter will go through the literature that is used as a basis throughout this thesis. It will also present related applications and research that will be compared based on their qualities.

2.1 Virtual reality

Virtual reality has several definitions depending on one's perspective. From a technical perspective, Burdea and Coiffet's [7] defines virtual reality as "a high-end user-computer interface that involves real-time simulation and interaction through multiple sensorial channels. These sensory modalities are visual, auditory, tactile, smell and taste." From the psychological perspective, VR is an experience and not a technology [6]. The feeling of presence is a vital element in this experience [6] and refers to the user's sense of being in a virtual environment [8]. To achieve this, the user needs to be immersed in the world, which is gained through interaction with the environment in the same way one would interact with the real world.

2.1.1 Virtuality continuum

There are many forms of reality; they can be sorted from the real environment on the one side, to the virtual environment on the other (see Figure 1). The real environment is the real world we live in. Augmented reality (AR) adds computer-generated elements onto the real world. Augmented Virtuality (AV) is real-life content displayed in VR, similar to an immersive film. The virtual environment is artificially created without capturing any content from the real world [9]. XR is generally meant as a term for all realities except from the real one.

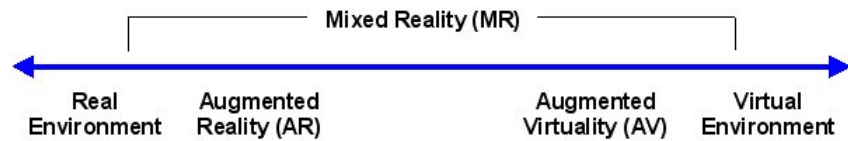


Figure 1: The virtuality continuum

2.1.2 The history of VR

VR can be traced as far back as the 1960s with Marton Heilig’s Sensorama (see Figure 2). The Sensorama was created for immersive films with a wide field of view, stereo sounds, seat tilting, vibrations, smell, and wind[9], almost like what we today call a 4D film.

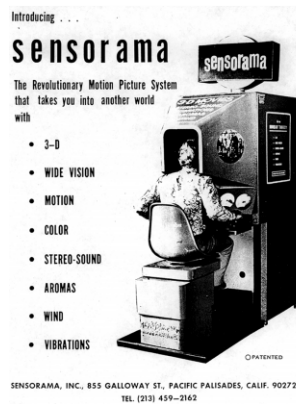


Figure 2: Marton Heilig’s sensorama

The first working head-mounted display(HMD) which successfully responded to the users head movement was created in 1961 by Philco Corporation engineers. In the 1990s VR exploded with a focus on location-based entertainment and professional research. The technology did not advance enough to keep the interest in VR alive, which started what is known as the "VR winter." Facebook bought Oculus rift in 2014, which started a new era for VR. Many large companies like, Valve, Htc, and Samsung also started to invest in VR technology in the following years. With these companies driving the technology forward, and access to affordable hardware, VR has become widely available to the consumers. VR is now available with the use of smartphones, as a standalone HMD headset, or as a fully immersive headset with hand movements.

2.1.3 Immersion and presence

Bob G. Witmer[10] defines immersion as "a psychological state characterized by perceiving oneself to be enveloped by, include in, and interacting with an environment that provides a continuous stream of stimuli and experiences." The user does not feel the same immersion when looking into the environment as opposed to being a part of that environment. What further strengthens the users feeling of being immersed is the ability to interact with the environment. These features are exactly what VR provides the user, and is, therefore, a great tool to provide a sense of immersion.

Immersion increases the user's sense of presence. Witmer[10] defines presence as "the subjective experience of being in one place or environment, even when one is physically situated in another." According to Bulu[8] presence is an important factor that affects the user's satisfaction, and improve learning.

2.1.4 Design principles of VR

The design principles presented below, are described in the book "The VR Book, Human-Centered Design for Virtual Reality" written by Jason Jerald[9].

VR sickness

Design principles are crucial for VR. If not done correctly, the user can get frustrated or in the worst case, feel physically ill. This sickness caused by a conflict in visual and vestibular cues can be compared to car sickness. This means that the user can start to feel sick in an environment that is moving, without the user moving in real life. It is, therefore, important to always have stable elements in the environment. If the application has to move the user, visual acceleration and rotation are to be avoided. Jerald[9] states that one can use constant visual velocity without much contribution to VR sickness, or the use of motion platforms if integrated into the design can also help to reduce motion sickness[9].

Audio and way-finding

In everyday life, auditory cues help people be more aware of their surroundings, and in VR, it is the same. It can have an emotional impact, cueing visual attention, and give information without taxing the visual system. This suggests that information such as language should be mediated through audio. Spatialized audio is sound that comes from a location within the 3D world and can be used to direct the user's attention in a certain direction.

There are several ways other than sound to guide the user to their current object, such as environmental way-finding aids. These are independent elements used to direct the user's attention. These should be easy to recognize and have distinct characteristics that stand out in the environment, such as objects with bright colors, glow, or pulsing lights.

Interaction

An intuitive interface is as important in the virtual world as in any other program, if not more so. To create an intuitive interface one can look at Don Normans interaction principles[1]. Affordances define what actions are possible and how something can be interacted with by a user. Many affordances of items in the real world transfer over to the virtual world. For example, smaller objects afford the action of picking them up, a table affords a place where one can put an object.

The relevant affordances of an application should be perceivable by the user[1]. If an object does not have any perceivable affordances, then one can use signifiers such as signs, labels or images to help the user understand what to do.

Affordances are the possible interactions an object offers a person [1]. Signifiers are cues helping users discover the affordances of an object. However, some signifiers can be accidental and give users the wrong affordances [9]. One example is an object that looks like it can be thrown but really is an integral part of a puzzle, and this may have the user throw that part away.

Feedback is an especially important design principle for VR. Feedback can be thought of as a communication between the user and the system. This is a way for the system to show the state of the object that is being interacted with [9]. The most important feedback in VR is the responsiveness when looking around or moving the hands. If this is unresponsive, it can lead to a loss of immersion or VR sickness.

Mapping can be a powerful tool that gives the user information about an element [9]. Mapping is used to show a relationship between two or more things[1]. This can be done through signs, symbols, and patterns, but also from the shape of an object.

Affordances	Affordances define what actions are possible and how something can be interacted with by a user.
Signifiers	A signifier is any perceivable indicator that communicates appropriate purpose, structure, operation and behavior of an object to a user.
Constraints	Interaction constraints are limitations of actions and behaviors.
Feedback	Feedback communicates to the user the results of an action or the status of a task.
Mappings	A mapping is a relationship between two or more things.

Table 1: Don Normans design principles [1]

2.2 Serious games

The number of serious games both for training and education has increased the last decade[11]. Serious games are games where entertainment is not the main purpose, but it still uses a game structure[12]. The purpose can be everything from training firefighters and health personnel to teaching a new language. One example is the use for prevention of bullying by improving social abilities and increasing childrens' awareness about the issue[13]. Backlund and Hendrix[11] conducted a literature survey of the effectiveness of serious games. 29 out of the 40 studies showed a positive result on learning. Thirteen of the studies they looked at were in the field of mathematics. Only 7 had a positive result, while 5 had neutral results and one had a negative result. They did, however, in general, find positive effects on motivation.

2.2.1 Strengths and weaknesses

Games have both strengths and weaknesses when it comes to learning. Games give the user intrinsic motivation to continue playing, and specific goals the user can aim for[14]. They can also bring a rich and appealing environment and an engaging storyline. Games can give immediate feedback and provide a high level of interactivity. These are characteristics that, according to Dörner[14] are in line with almost all pedagogical theories or instructional design approaches. However, there are also weaknesses such as the balance between playing and learning, or between challenge and ability. One may be at the expense of the other.

2.2.2 Story

Dörner[14] describes a story as "a narration of events that are somehow connected." Stories have the ability to evoke emotion in humans, which can cause further immersion in the game. Emotional engagement is also important for learning efforts and motivation. Ideally, the users are engaged in the story and might even influence it.

2.3 Geometry

According to several researchers, geometry is one of the most important branches in mathematics[3][4]. Geometry is a way for humans to describe the world and is used all the time to perceive our environment. According to Laborde[15], the activity of teaching geometry must be considered with at least two aspects: the study of concepts and logical relations, and the spatial concept. Famous mathematicians like Hadamard and Einstein have suggested that spatial thinking is essential for creative thought in high-level mathematics[4]. Following Piaget and Inhelder's theory, the representation of space is built up from active manipulation of the environment [4]. Childrens' idea of

shapes comes from active interaction with objects. This knowledge is constructed in the mind with input from several senses[4].

2.3.1 Concept image

Vinner[16] uses the term "concept image," which is a person internal image of a concept. One example Vinner uses is that we do not have explicit definitions for houses, but we have a clear concept image of them. The teaching of geometry is based upon diagrams and visualization, and language to describe geometrical objects and relations[15]. Visualization is a powerful tool in geometry, but by using figures to teach geometrical concepts students can end up creating concept images that works specifically for that one figure. However, this concept image might be different from the concept definition [4]. It is, therefore important to have several different figures explaining the same concept. Students that have been instructed with the use of computers often score significantly higher than those with just classroom instructions. The use of computer programs such as Geogebra[17] gives the students the ability to manipulate geometric objects or representations of concepts. Clements gives the example of manipulating geometric representations of concepts as "rather than drag a shape to turn it, a "direct concept manipulation" interface might have students manipulate a representation of a turn, including turn center and amount of rotation." Clements also states that manipulating a representation of concepts leads to higher achievement than manipulating the shape directly.

2.3.2 Stages of learning

In Pierre and Dina van Hiele's theory, students progress through levels of thought when learning geometry. Clements describes four levels as following[18]:

1. The visual level, in which students can recognize shapes only as wholes and cannot form mental images of them.
2. Students recognize and characterize shapes by their properties.
3. Students can form abstract definitions, distinguish between necessary and sufficient sets of conditions for a concept, and understand and sometimes even provide logical arguments in the geometric domain.
4. Students can establish theorems within an axiomatic system. They recognize the difference among undefined terms, definitions, axioms, and theorems and are capable of constructing original proofs.

Hiele's theory also includes a way for teachers to move a student from one level to the next level. This model consists of five phases which Clements describes[18]:

1. Information, the teacher places ideas at students' disposal.

2. Guided Orientation, the teacher engages students actively in exploring the object, such as folding and measuring, so as to encounter the principal connections of the network of conceptual relations to be formed.
3. Explication, the teacher guides students to become explicitly aware of their geometric conceptualizations, describe these conceptualizations in their own language, and learn traditional mathematical language.
4. Free orientation, students solve problems whose solution require synthesizing and using those concepts and relations. The teacher's role includes selecting appropriate materials and geometric problems with multiple solution paths; giving instructions to permit various performances and encouraging students to reflect and elaborate on these problems and their solutions; and introducing terms, concepts, and relevant problem-solving processes as needed.
5. Integration, teachers encourage students to reflect on and consolidate their geometric knowledge, with an increased emphasis on the use of mathematical structures as a framework for consolidation, and eventually place these consolidated ideas in the structural organization of formal mathematics.

The student will have advanced to the next level upon the completion of phase 5. The teacher's role in these phases are somewhat limited, only in phase 3 and 5 does the teacher need to direct the learner's intention.

2.3.3 Feedback

Researchers generally agree that feedback is one of the cornerstones of all learning[19]. One problem is that many students are not satisfied with the feedback given by teachers. As summarized by Orell[19], some researchers argue that this failure comes from the students' inability to understand the feedback provided, because it is explained in the "expert" language of academic disciplines. Orell found that feedback was focused around the students' errors, and resulted in a negative impact on the students' egos. This does not mean that one should avoid negative or constructive feedback. Both positive and negative feedback is important, and the most useful feedback usually contains both[20]. Phil Race[20] mentions five attributes of good feedback:

- Timely - the sooner the better
- Intimate and individual
- Empowering
- Feedback should open doors, not close them
- Manageable

2.3.4 Research on area and volume learning

Owens research shows that students do not connect area and volume to the number of rectangles and cubes but sees it as an abstract concept of multiplication[21]. One reason for this can be that many prospective primary teachers only teach the formula and not how the formula works which is often the result of procedural thinking and not conceptual. The way students learn does not fit with the way they are taught the formula. Outhred and Mitchelmore[22] suggests that counting arrays is a great way for students to learn about area, which gives a better understanding of the formula.

Students understanding of the volume of rectangular prisms do not go much further than a number obtained by multiplying the measurements length, height, and depth[21]. Research done by Battista and Clements[23] shows that students could not build a mental model of a 3D-object based on separate views of the same 3D-object.

2.3.5 Mathematical anxiety

A common problem is mathematical anxiety; it hinders the student's achievements in mathematics [24]. It is defined as a feeling of tension, apprehension, or fear that interferes with math performance. Math anxiety can result in the students avoiding math, which has negative results on their achievements. There are some ways to reduce math anxiety and in relation to our research, the relevant ways are: the use of adaptive computer math programs and increasing the math activities that are done at home. In this case, adaptive computer math programs are programs with tasks that are adapted to the level of the user.

2.4 XR for learning mathematics

In the last few decades, the use of technologies in education has spread rapidly and the educational theories directing their design have had to change in response to this. VR, as one of these technologies, was in need of such theories to become usable in education. Today the typical consensus is that constructivism should be the basis for these theories [25] [26] [27]. In constructivism, knowledge is something that is constructed based on the experiences of a person. The person gains experiences through perceiving and interacting with the world. The experiences gained through conventional education are typically third-person experiences, that is, gaining knowledge through a third person source rather than from a person's own experience. They are also typically symbolic, using data such as text and graphs to abstract the world. This is in contrast to the principles of constructivism which supports first-person experiences and non-symbolic interaction.

Other theories connected to learning in VR are Autonomous learning and cognitive load theory (CLT) [27]. Autonomous learning is when students choose their own learning goals, learning methods and assess their own learning outcomes. VR can allow for this by giving the student control over

the learning environment, giving the option of repeating their practice as much as they want and giving them the necessary feedback needed to check their learning. CLT, however, goes more into the problems of overloading the mind with input. In relation to VR, this theory shows the importance of not adding too much stimulation into one's environment because it can limit the attention and working memory of the user. Not having as rich environmental stimulus might, however, affect the immersion which is also important for learning in VR.

Through immersive VR, students can interact with the world using the "natural semantics" of the world [25]. The immersion permits the student to gain first-person experiences and interact with the world non-symbolically, the same way they would in the real world. This makes VR a good tool for training in simulations of real-world scenarios, especially those scenarios that are impractical, costly, or dangerous to conduct in real life [28]. Examples of such training are its use in military training and surgical procedures. Here the users can conduct their training in a low-risk environment that gives them real-world mastery of techniques before they are needed in real life.

VR is effective for training in real-life simulations, but by using VR one could even gain experiences in settings impossible in the real world. Winn [25] describes three kinds of knowledge-building experiences that do this: Size, Transduction, and Reification. Through changing the size of participants and virtual objects in relation to each other, students can gain insight into everything from the molecular structures of crystals, to the orbits of planets.

Transduction experiences make typically unavailable sensory input available to users. Examples can be seeing infrared light or taking the role as a bat and visualizing its echolocation. The third kind, Reification, is experiencing perceptible representations of abstract concepts. This can be done by creating an interactive and perceivable representation of, for example, algorithms or the Pythagorean theorem. It is important to state that all this is done while still giving the user an immersive first-person experience, even though the experiences are not possible in a real-world setting.

2.4.1 XR for Geometry

As we discussed in the previous chapters, there has been much research on the use of technology and games in teaching mathematics and geometry. However, VR is a technology that has not been widely researched and used for this cause. Most of the research is on AR applications where users can manipulate objects to learn specific principles in geometry.

One example is Construct3D that was shown to both facilitate the learning of geometric constructions and make it easier to learn [29]. In this application, the user can create different objects such as points, lines, planes, cubes, spheres, cylinders, and cones, see Figure 3. There is also support for visualizing different geometrical principles such as intersections and symmetry operations. The application has modes for use alone, with other students or as a teacher teaching students. In their evaluation, they found that the hypothesis: "that actually seeing things in 3D and interacting with

them can enhance a student’s understanding of 3D geometry” was supported by their anecdotal evidence.



Figure 3: An example of using Construct3D

The mixed reality application Mathland tries to teach students about mathematics and physics [30]. To give an immersive experience they use the Microsoft HoloLens, an arm controller that uses the natural motion of the arm and a tangible object controller to manipulate virtual objects in a lifelike manner. The creators stated that through the use of Mathland users can both visualize mathematics in an immersive way, but also construct new projects and experiment with the world. An example of its tasks is presented in Figure 4.

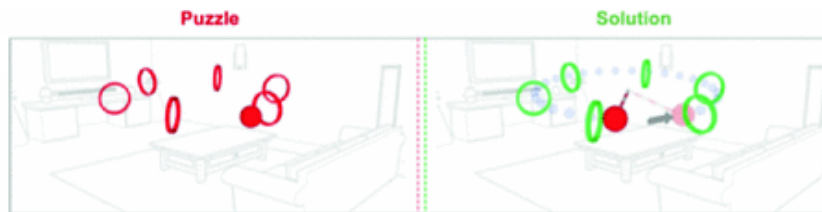


Figure 4: An example of a task in Mathland

ARDehaes is an application with an augmented book whose goal was mainly developing spatial abilities in students and some introduction to technical drawings, seen in Figure 5. It was shown to be able to increase students spatial abilities. However, it used a regular computer screen to display the book and its augmentation, but allowed for interaction with the geometric objects by rotating and moving the book [31].

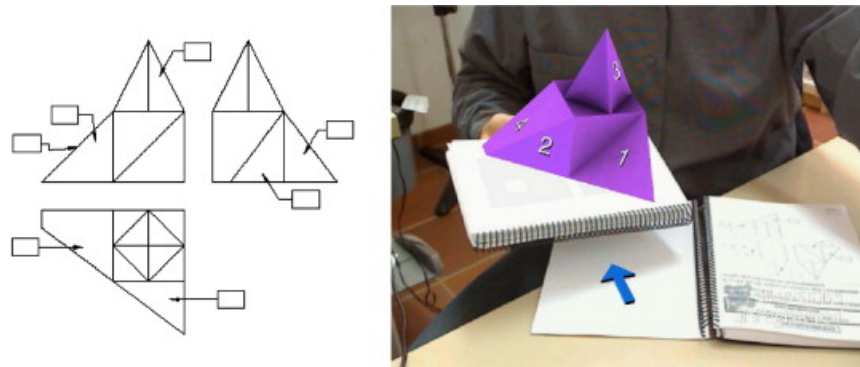


Figure 5: Student using the augmented book ARDehaes

Hao-Chiang[32] also created an application displaying augmentation on a computer screen. The application was used in a lesson taught by the researchers, see Figure 6. They found that the use of the system for teaching gave positive results on the spatial ability of students with average or low academic achievements. They also found that spatial abilities had a high positive correlation with student achievements and therefore highlights the importance of developing spatial abilities in students.



Figure 6: A class being taught through augmented visualization

One immersive VR application for geometry is Geometry Explorer [33]. This application, using a Samsung Gear VR HMD, set out to teach students about the volume of different 3D shapes. The application allows users to manipulate the volume of a rectangular prism by dragging widgets in three dimensions, as seen in Figure 7. They also added a score system as a game element, where the students would manipulate the shapes into correct volumes as fast as possible to gain higher scores. A high-score list was also made to add to the motivational factor. Using the Rapid Iterative Testing and Evaluation approach, they discovered problems with their prototype that could be of use to others when designing similar applications. One relevant problem they discovered was the fact that students struggle with mental calculations of 3D formulas. A 3D multiplication matrix was

used to ease the difficulty of mental calculations and instead focus on the formulas that were the focus of the exercises. The future work of the paper states that they were in progress of a summative evaluation of the application. However, we could not find any further information about this.

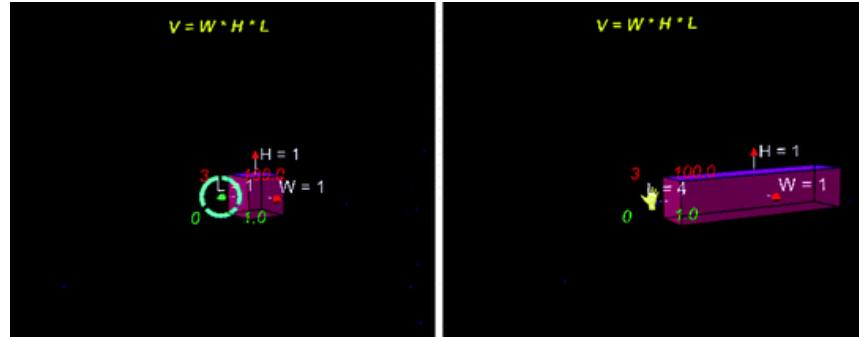


Figure 7: Screenshots from Geometry Explorer illustrating the manipulation of objects

2.5 Comparison between learning applications

The applications described in the previous section were compared with each other. This comparison on some main features can be seen in Table 2. A checkmark (✓) represent which feature exists in the application. The features we took into account are explained in the list below.

- **Game elements** — In this case, we were looking for any aspect of game elements. This can, for example, be a story, or competition between users.
- **Room-scale** — An application with room-scale is an application which allows the user in the play area free movement.
- **VR** — VR here being the use of stereoscopic HMDs blocking out visual input from the real world.
- **3D object manipulation** — By this we mean the capability of changing parameters of 3D objects.
- **3D object interaction** — By interaction, we mean the ability to interact with 3D objects in general. E.g., moving and rotating 3D objects.
- **Environment** — An environment here is a virtual 3D environment that users can traverse.

Applications	Features						
		Game elements	Room-scale	VR	3D object manipulation	3D object interaction	Environment
Construct 3D		✓			✓	✓	
ARDehaes						✓	
Hao-Chiang application						✓	
Mathland		✓				✓	
Geometry Explorer		✓		✓	✓	✓	
Our application		✓	✓	✓	✓	✓	✓

Table 2: User needs from Section 4.1.1 connected to requirements

The table shows that from the applications we found, few have researched the use of VR for geometry education. Further, the use of a traversable environment is something not found in VR geometry applications today. Geometry Explorer used game elements; they did, however, not use a room-scale setup or an environment. In addition, they did not do any testing to find what effects the application could have. From this, one can see that there is limited research on the use of VR for geometry. The research on these applications shows that manipulation of and interaction with 3D objects are positive for learning, but these effects have not been tested for with VR.

3 Method and Equipment

This chapter will describe the methods used to conduct the research and how development was organized. Further, we describe the software used for the development of the application, and the hardware used for testing and evaluating the product.

3.1 Method

Several methods have been used to create the application and to evaluate the product. Our main research strategy was "design and creation," as is described in the book by Oats [34]. The design and creation method focuses on developing new IT artifacts, which suits our goal of creating an application for learning geometry in VR. The steps from this strategy are:

- **Awareness** — Finding the problem
- **Suggestion** — Creating ideas of how to solve the problem
- **Development** — Where the idea is implemented
- **Evaluation** — Examining the worth of the implemented artifact
- **Conclusion** — Where the knowledge gained is identified

The steps suggestion, development and evaluation where followed in two iterations which is recommended in the book by Oats. This resulted in phase 1 and phase 2 that are described in chapters 4 and 5.

Several methods were used to gather data. We used questionnaires, observations, and semi-structured interviews, as described by Oats [34]. The questionnaires, observations, and semi-structured interviews were used to gather results and evaluate the application in both phase 1 and phase 2. The data gathering in this project was approved by the Norwegian Centre for Research Data (NSD)[35]. When recording interviews, the participants signed a formal consent form, seen in Section A.1, agreeing that their data would be stored and processed until the end of the research project. All data gathered through the questionnaires where anonymous.

As the didactician in mathematics recommended to not test the learning outcome from the application through a test group, focus group, and a control group. This would take a lot of time and would be outside the time frame of this project. The decision was therefore made to measure the students' self-efficacy on their ability to improve their own understanding. This was done with a Likert scale ranging from one to five.

The results gathered from questionnaires, were then analyzed and presented in graphs. In the final evaluation of Phase 2, see Section 5.3, the questionnaire was divided into pre and post questions. Some of the results from these questionnaires were then compared by using the "Wilcoxon matched-pairs signed-ranks test" from Stata [36]. This test was used to check for statistically significant differences between data from the pre and post questionnaires, using a significance level of 5%. A significance of under 5% suggests that the results are not attributed to chance.

3.2 Software

The development in this project depended on different types of software to be available. This section will describe the software that was used during the project.

3.2.1 Maya

Maya is a 3D animation, modeling, simulation, and rendering software created by Autodesk[37]. The software is free for students and cannot be used commercially without a paid license. The use of this software is covered by the student licence as it permits the use of this software for learning, training, or research[38]. Maya 2019 was used to create some of the 3D models for the learning application.

3.2.2 Aseprite

Aseprite is an animated sprite editor and pixel art tool which is used to create 2D animations for video games[39]. This software was mainly used to create the animations used in the tutorial to teach the users the basics of VR movement and interaction.

3.2.3 Unity

Unity is a game engine and a real-time development platform[40]. It is free as long as the revenue or funding does not exceed 100K dollars per year. The platform provides support for building the software to several platforms such as PlayStation, Xbox, Android, windows, and more. Unity has a large community that help each other through various forums and the asset store. The asset store is a place where creators can share or sell 3D-models, scripts, textures, or other elements.

Unity supports a wide variety of technologies, and many third parties have created useful plugins for the platform, such as SteamVR. SteamVR is a plugin for Unity created by Valve which adds support for different types of VR-headsets[41].

All of this made Unity eligible to use for the development of the application. The final version of the application was created with version 2018.3 of Unity as version 2019.1 came at the very end of the development.

3.2.4 Stata

Stata is a statistical software [36] that can be used for things like statistical analysis, simulations, data management, and more. We used the software for creating graphs and calculating statistical significance.

3.3 Hardware

The application can potentially support many types of VR-headsets by the use of SteamVR, but this section will only cover the ones used during the development and testing of the application.

3.3.1 HTC Vive

HTC Vive is a virtual reality headset developed through a partnership between HTC and Valve[42]. The HTC Vive is a fully immersive headset with a 360-degree controller and headset tracking. It is important to note that the setup is a room-scale system that physically allows a user in the play area free movement, as opposed to a stationary where only the head movements are tracked. The controllers are wireless and provide the user with free hand movement. The headset comes with a resolution of 2160 x 1200 pixels, which provides a good experience for the user. There is also a pro version of the HTC Vive which has a resolution of 2880 x 1600 and support for 3D spatial audio to provide the user with an even better experience[43]. Both versions were tested when developing the application, and both versions worked well, but the HTC Vive Pro was preferable.

3.3.2 Oculus rift

Oculus Rift is a virtual reality headset developed by facebook[44]. The Rift has two wireless touch controllers that provide the user with free hand movement. The headset has 360-degrees tracking, but the controllers can struggle at some angles when losing sight of the base stations. The headset has a resolution of 1200 x 1080 pixels for each eye, which provides a good experience for the user. The application was not initially developed for the Oculus Rift but was sometimes used when testing due to practicality issues. The application works just as good with the Oculus Rift. It does, however,



Figure 8: Htc Vive Pro headset

have one issue: the fact that the base stations sometimes lose tracking of the headset when a user faces away.



Figure 9: Oculus rift headset

4 Phase 1

This chapter will go through the first iteration of the development and how the idea and application were formed. First, some basic user needs were created, which lead to the requirements for the application together with research from the background and related works. Further, the design choices are justified before representing the result of the evaluation of phase 1.

4.1 Exploration

At the very first stages of the project, we did not know precisely in which direction to go other than utilizing VR for mathematical education. After a literature review was conducted, it became clear that there was an overall agreement between researchers that constructivism is best suited for learning and teaching in VR. We contacted several didacticians of mathematics to discuss thoughts and ideas and figured out that geometry was well suited for the affordances VR had to offer. They also mentioned that most people do not have a spatial understanding of the connection between real-life sizes and their measurements, an example being most people can not visualize $1m^3$. We kept in touch with one of the didacticians for further input and feedback.

It was desirable that the application could be used without the presence of others since mathematical anxiety is a well-known issue when around others, see Section 2.3.5. As the user was alone and not forced to learn or explore, the application had to provide the user with the motivation to use it. Games have proven to motivate students and do not have a negative learning impact on students when done correctly, see Section 2.2. This led to the decision of adding certain game elements like an exciting environment and some basic story elements.

The target audience for this project was students at high school with the subject P1 or P1-Y. This target audience was chosen on the basis of their syllabus in geometry and the accessibility of students. Their syllabus contains both area and volume of different figures[45] which fits perfectly with VR.

4.1.1 User needs

After the exploration phase, we had a general idea of the user needs and what the application should provide the user. These are the user needs the first version of the application was based upon.

1. **Easy to use** — The application should be intuitive and easy to use. With regard to the target audience, everyone should be able to use the application without much guidance, both those who have experience with VR and those who do not. Problems with using the application can draw focus away from learning and cause frustration thus resulting in an inefficient learning experience.
2. **Learn Geometry** — The application should give the user a better understanding of area and volumes of rectangular prisms and pyramids. The user should learn about the underlying concept of the formula and not just how to use the formula. As mentioned earlier, see Section 2.3, spatial reasoning is an essential part of geometry. One of the benefits with VR is that one can move around and manipulate objects in space, which makes VR great for illustrating concepts of area/volume calculations.
3. **Learning differently than standard learning methods** — The application should give the user an alternative learning method than the standard classroom method. As presented in Section 2.3.4, the way students learn does not always fit with the way they are thought. VR can give users a first-person learning experience, together with body movement, which is shown to improve learning.
4. **Motivation** — The application should motivate the user to explore mathematical concepts to get a better understanding. From talks with didacticians the fact that many students are not motivated when learning maths and might, therefore, have difficulties with the subject.

4.1.2 Requirements

1. **The application should have specific tasks to solve.**
Hiele's theory states that teachers should engage the students actively in exploring objects, see Section 2.3.2 about stages of learning. The application should take the role of the teacher and use tasks to actively engage the user.
2. **The user should have access to all the information necessary to create the right concept image of the concept at hand.**
Hiele's theory also stated that teachers need to place ideas at students' disposal, see Section 2.3.2. The application in the role as the teacher needs to present all the information necessary. Without this information, students might end up creating the wrong concept image in the same way that figures can create the wrong concept image, see Section 2.3.1.
3. **The application should give the user time to explore and reflect around the concept.**
Following phase 4 of Hiele's theory, the user should have free orientation and should reflect and elaborate on the problems and solutions, see Section 2.3.2.

4. The user should be able to physically interact with and perceive their environment to solve tasks, similar to real life.

The ability to physically interact with objects supports immersion, as described in Section 2.1.3. Being immersed is also important for getting first-person experiences, as presented in Section 2.4.

5. Should have a tutorial to teach the controls and interactions used within the application.

Not many users have much experience with VR and should get help figuring out the basic controller interaction.

6. The application should use certain game elements.

Using game elements can motivate users, as presented in Section 2.2.

User needs	Requirements
1. Easy to use	1, 4, 5
2. Learn geometry	1, 2, 3, 4
3. Learning differently than standard learning methods	3, 4, 6
4. Motivation	4, 6

Table 3: User needs from Section 4.1.1 connected to requirements

4.2 Development

The development of the application started with a process of brainstorming ideas for tasks. From these ideas, we chose a few ideas that were reasonable and possible in the projects time frame. The main idea for the application was that there would be a learning space and a task space. The learning space would be more explorative and would prepare the users for tasks they were to solve in the task space. The learning space was designed to let the users use as much time as they wanted for them to understand the concepts. They also had the ability to go back if they got stuck in the task space. The task space has tasks to test their new knowledge and was set on the planet Mars. The tasks would be related to their mission on Mars that was setting up a base. Different parts of the applications and their development will be described in further detail below.

4.2.1 Teaching the concepts of area and volume

The first part of this version was the learning space about the area and volume of rectangles and rectangular prisms. One of the things we wanted the users to experience was the real-life sizes of the measurements they hear about. Not many people can visualize $1m^3$, as mentioned by the

didacticians in Section 4.1, and we wanted the users to get a more personal relationship between the sizes and themselves. The primary learning goal of this part would be how to find the area and volume of these shapes.

The handles on the blue hovering rectangle and rectangular prism (see Figure 10) are movable only on one axis. When pulling on one of these handles, the object will be scaled in the axis of the handle. The handles were colored red, green and blue to distinguish them from one another, but also because it is the typical colors of the axis widget in 3D modeling software.

In this part, there is also a $1m^3$ cube made out of 1000 $1dm^3$ cubes. By pressing a button, the big cube collapses into the smaller cubes. The thought behind this was to make the users experience the big size difference between $1m^3$ and $1dm^3$, but also teach the fact that $1m^3$ is equal to $1000dm^3$. The trigger of this is a big red button (see Figure 10). It affords the action of pressing it, and the red color makes it highly visible for the user. The smaller cubes can be picked up and thrown to allow the user to have some fun and learn a skill necessary for some of the following tasks.

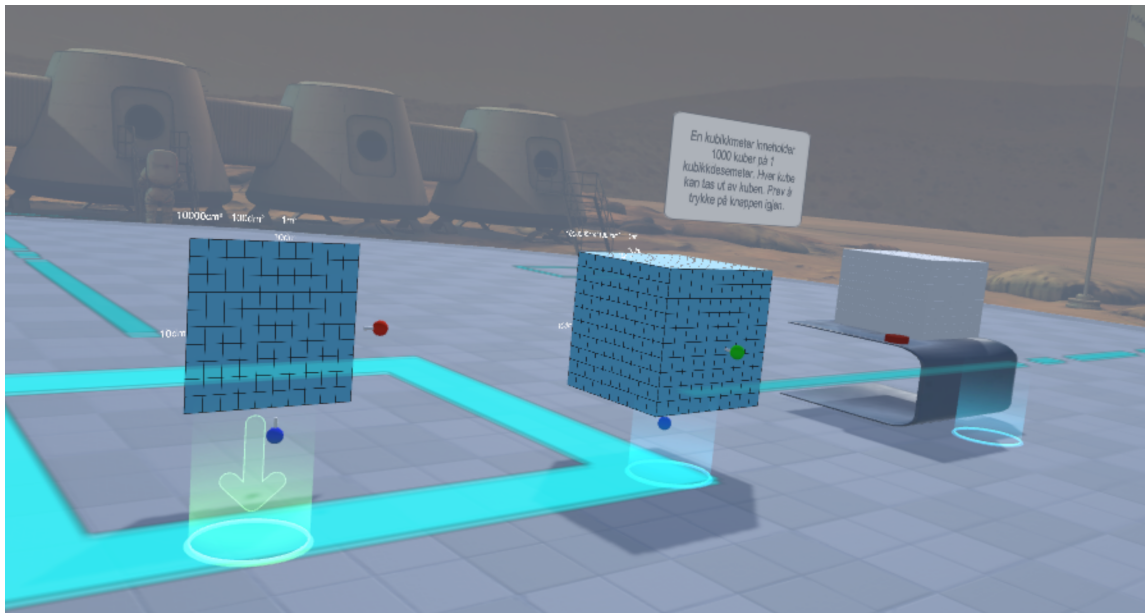


Figure 10: Teaching area of rectangles and volume of rectangular prisms

4.2.2 Area and volume task

The first task the user performs on Mars is to build a potato farm for the base. This is done from a platform 20 meters above the ground. To complete this task, the user needs to place three modules with different volumes or areas. One of the modules must have an area of $200m^2$, and the other two must have a volume of $50m^3$ and $100m^3$ respectively, see Figure 11. This task will test if the user

understands the concept from the learning space, while they experiment with sizes at a relatively huge scale to get a better understanding of real-life sizes.

The interaction with the modules is done with a laser pointer, which is used to select the different elements. The system works like a drag and drop system where one can drag the modules around by "clicking" on them. Each module also got arrows at each side that can be dragged back and forth to change the size of the module, see Figure 11. Every intractable element changes color when being hovered by the laser, and changes color again when "clicked" on. The module will also turn red when outside the "legal" placing area for the task. These changes of colors is a type of feedback that explains the state of the elements, which follows Don Normans design principles[1].

The flying platform was added so that the users would not have 20 meters of open air beneath them as not to scare them. The users will need to teleport onto the platform at ground level and press a button. This button is also a big red button to be designed consistently with the other buttons in the application. When pressing the button, the users are teleported up above ground. The choice of teleportation vs. lifting the user was done due to the fact that moving a player avatar without the user's control can be especially uncomfortable and nauseating for some people (see Section 2.1.4).

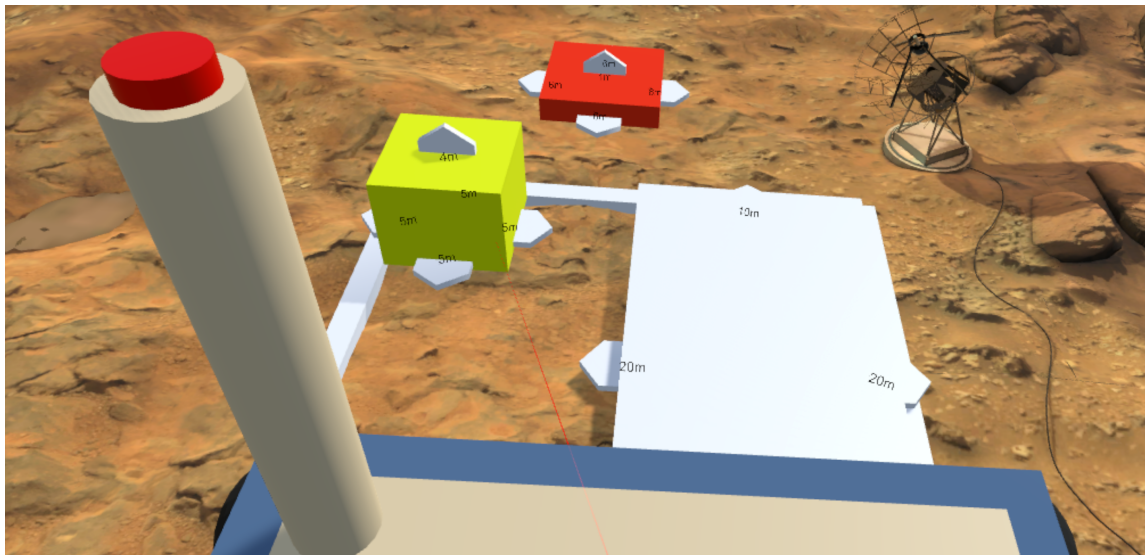


Figure 11: Volume and area task

4.2.3 Teaching pyramid volume

The volume of a pyramid was the second concept the users should explore through the application. This teaching space includes an interactive puzzle of some sort, where the users should physically build a cube out of pyramids. This was designed as a puzzle to give the user motivation to explore

the concept. The idea was that the users should already have learned about the volume of rectangular prisms from the previous tasks and could use this knowledge to further understand new concepts. By building a cube out of three pyramids, the users should see the connections between the volume of a rectangular prism, which was learned in the first part of the application, and the volume of a pyramid. When the user is done building the cube, the application tries to make them reflect by the use of guiding text before sending them to the next task.

The pyramids are standing on a table to give the user a surface to work on with the pyramid shapes. This work surface affords the action of placing down a pyramid and then repositioning their hand so that rotation becomes easier. In the center of the table, a wireframe of a cube is visualized to show that there is some room to be filled up. When the pyramids are placed close enough to a valid position in the wireframe cube, the pyramid snaps into this position. Using VR controllers, the users lose the finer controls of using their own hands. Because of this, the range where the pyramids would snap into place had to be big enough to account for the less precise movements. On the table, there are four pyramids while only three are needed to solve the puzzle. We did not want to make the answer obvious from the start and chose to solve this by adding the fourth pyramid. The pyramids have a patterned texture to make their shapes more perceivable for the user (see Figure 12).

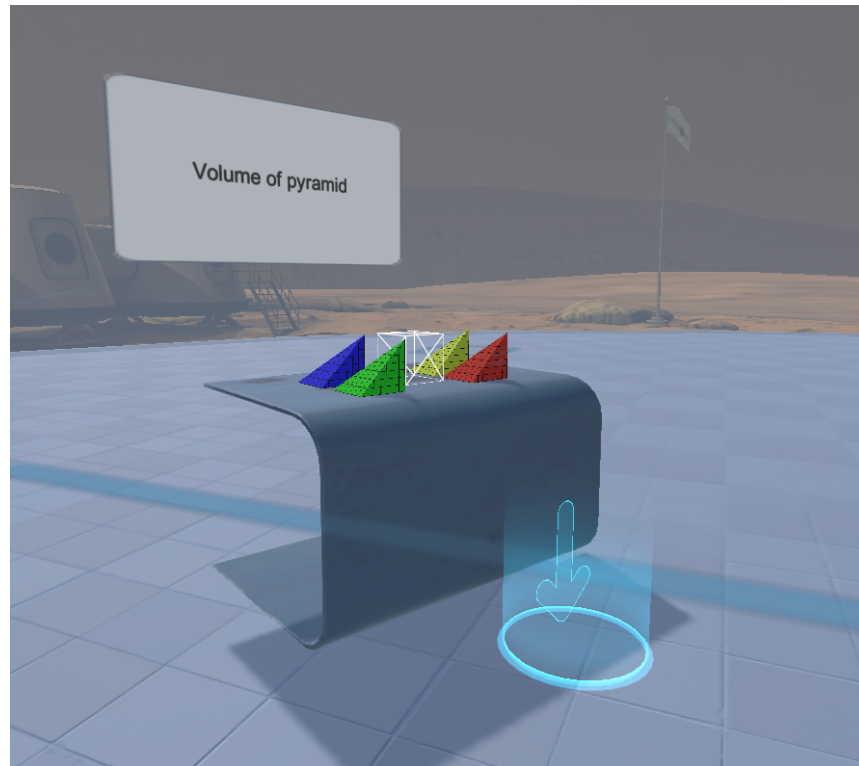


Figure 12: Teaching volume of pyramid

4.2.4 Pyramid volume task

This is the last task of the application where the user should use their knowledge of rectangular prisms and pyramids to water the potatoes from the first task on Mars. The task contains water tanks in different shapes and different sizes, see Figure 13. The potatoes need 35 liters of water, which can only be done when using the pyramid, thus requiring knowledge of pyramids to complete the task.

The watering device was made to make the act of putting water tanks into it entertaining for the user. When a water tank enters the watering device, a wall quickly pushes the tank into the display area. The display area is a closed-off chamber that the user can see into, so they always know what tanks they have chosen. The user can also reset the device and the tanks by pressing a red button. The device will flash a red light when the amount of liters added exceeds 35 liters. As mentioned in Section 2.3.3, this feedback is important for users to be able to experiment and learn.



Figure 13: Volume of pyramid task

4.3 Evaluation of phase 1

Evaluating the application in phase 1 was done by testing the application with high school students from two different schools, an expert in didactics of mathematics and with students of pedagogy at NTNU. The high school students answered a questionnaire after testing the application, we conducted a semi-structured interview with the expert in didactics of mathematics and interviewed the pedagogy students. Observations were also gathered on one high school's students. Some of the minor issues found while testing with the expert was fixed before testing with high school and pedagogy students. The results gathered from this evaluation were the basis for the changes made to requirements described in Section 5.1 and further development of the application in the second phase, see Section 5.2.

4.3.1 Expert in didactics of mathematics

A test was conducted with an expert on didactics of mathematics. The expert tested the application on an HTC Vive and answered a brief semi-structured interview. The results divided into strengths, weaknesses, and recommendations for future work, will be presented below.

Strengths

The feedback on strengths was that the tasks were in general good and had important learning outcomes. The expert especially liked the thought of presenting measurements as real-life sizes so that students can get a better spatial understanding of them. Being able to pick up and interact with objects could give users a more personal experience of the concepts, and at the same time making it more engaging and fun. From this, we see that the expert agreed on the main ideas of the application. However, there where much room for improvement.

Weaknesses

The expert started by giving thoughts and issues on concrete parts of tasks, for example, the fact that an asterisk (*) had been used instead of a multiplication sign. The tasks, in general, where good, but some lacked fun elements like more interesting visuals and animations. The expert also mentioned that giving the user a reason for why they needed to solve the tasks could help with motivation. The importance of feedback was also mentioned. Most of the tasks had some feedback for when tasks were done correctly, but adding more immediate and auditory feedback would improve the application. The expert did not understand the reason for having a split environment between learning and solving tasks. This could mostly only be confusing and suggested that everything could fit in one environment. More exploration in the environment and tasks could also add to the motivation and engagement of the user. The tasks were a bit to instructional, and the users never had to move so they could see the environment. There could also be some problems with doing all the calculations in the application without any aids.

Recommendations for future work

The expert mentioned a few things that they would want in such an application. One such element was displaying the Pythagorean theorem and visually proving it while letting the user interact with it. When focusing more on volume and area, the expert mentioned that one could build up volumes with snow, so that one would experience the sizes in an even more personal way. The expert recommended to keep focusing on area and volume, but also to look more into conversions between measurements. Other recommendations where adding fun sounds and visuals as talked about in the previous section. To give the user more reason for doing tasks, the expert suggested that we could add a deeper story, points, or some other gamification elements.

4.3.2 high school students

The application was tested with a local high school at the IMTEL VR-Lab. In total, ten students tested the application and answered a questionnaire. The VR equipment used was HTC Vive. Four students at a time tested the application in four semi-separated rooms. Our role was introducing the students to VR and the application, but also to help struggling students and taking notes of

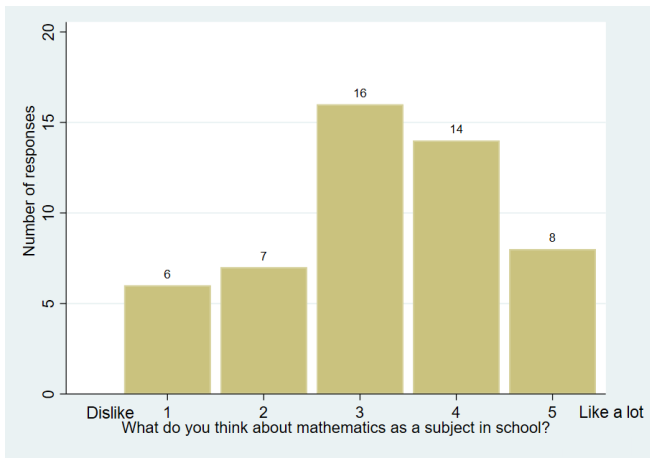


Figure 14: What students think about mathematics as a subject in school

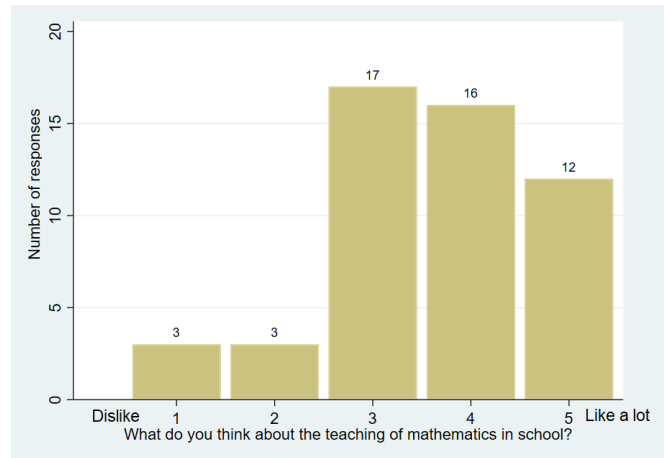


Figure 15: What students think about the teaching of mathematics in school

observations. The questionnaire was conducted on a computer after testing the application.

A different high school in a different city also tested the application in their own VR-lab. We sent them the application, and they conducted the tests themselves with teachers as instructors. Forty-one students tested the application with HTC Vive headsets and then answered the questionnaire on paper.

During testing questions in the questionnaires were written in Norwegian. The questions have been translated when presented in this section. The original questionnaire can be seen in Appendix A.2. The result for both of the tests will be presented below.

Thoughts on mathematics

16% of students gave their rating as 5 when asked what they thought of mathematics as a subject in school, where 1 was "dislike," and 5 was "like a lot." 27% answered 4, 31% answered 3, 14% answered 2 and 12% answered 1, see Figure 14. From this, one can see that most of the test groups are neutral to the subject of mathematics. They are, however, slightly more positive towards the teaching of mathematics in school as seen in 15. In this question 24% gave the rating 5 while 31% rated it 4. 33% rated it 3, 6% rated it 2 and 6% rated it 1. 23 students answered the question asking for reasons for liking or disliking mathematics. The answers were categorized into the four categories: Teaching, Relevance, Skill, and Interest. There were both positive and negative answers in all the four categories as one can see in the two diagrams in Figure 16.

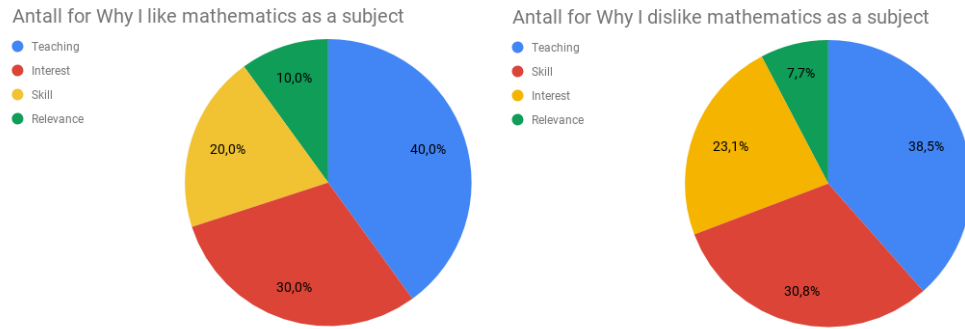


Figure 16: The different types of responses on why students like (left) or dislike (right) mathematics as a subject

Thoughts on the application

The application got good scores from most students when they were asked to rate the application from 1 to 5, as seen in 17. 35% of students gave the application a rating of 5, 33% a rating of 4, 14% gave a rating of 3, 6% rated 2, and 4% rated the application 1. The rest did not rate the application. Thirty-nine students gave a written comment on what they liked the most about the application. Most students thought that it was exciting and fun, while many students also commented that it was fun to try the VR-technology. The novelty of VR could have an impact on why many students liked the application. Other students commented that they believed it could make it easier to learn and that it was interesting to learn in a new way. Twenty-two students also gave a comment on what they liked the least. Most of the comments pointed towards issues with knowing what to do and how to do it, indicating a lacking user interface. Many also commented that it was difficult to move around. This matched the observations of the test at the IMTEL VR-Lab. Many students struggled with understanding the movement by teleportation. We had to demonstrate how to move, often several times, before they were able to move around themselves. Other things the testers did not like were: the lack of sound, that the colors where boring, and they wanted a reason to complete the tasks. Several students also mentioned that they thought the tasks in the application was too easy or too difficult; some also wanted more to do and more tasks. There is a limited amount of tasks in the application, and the difficulty of these might not fit with all students needs.

When asked if they had problems with any of the tasks, most that had any problems answered the pyramid volume task that is described in Section 4.2.4. Many also mentioned the area and volume task described in Section 4.2.2. The other parts were not mentioned. This also fits the observations where many students struggled with those tasks in particular. We also observed that many students struggled with solving the task described in Section 4.2.3, where one builds up a cube from three pyramids. The main issue was that there were four pyramids, but only three were to be used, which caused confusion. Another issue was that the different colors of the pyramids lead some students

to believe that they were also different in shape.

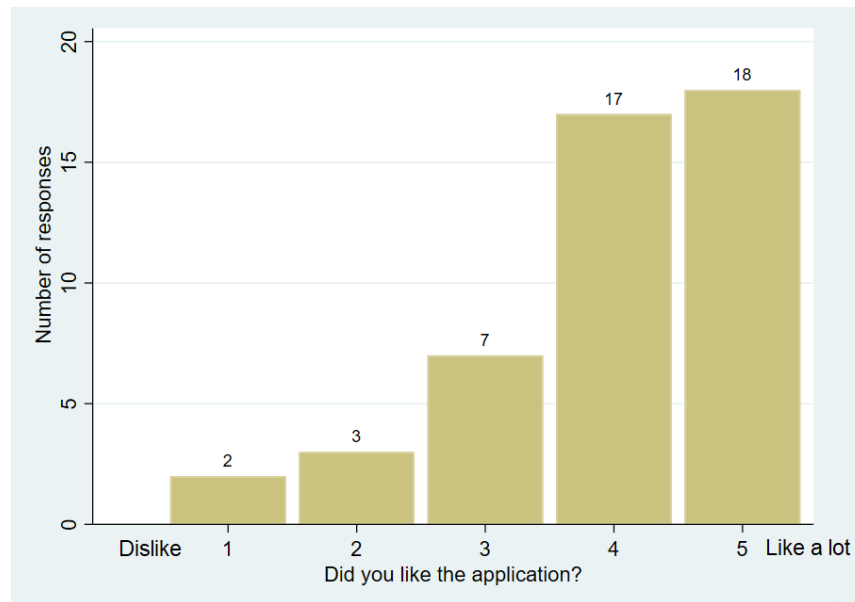


Figure 17: The students rating of the application

Understanding and engagement

The questionnaire also asked if the students got a better understanding of geometry by using the application. The students answered between 1 and 5, where 1 was "strongly disagree," and 5 was "strongly agree." 8% answered 1, 14% answered 2, 33% answered 3, 25% answered 4 and 20% answered 5 as seen in 18. The reason for the widespread of answers could be the difference in skill level. Some students may be so good that they learn nothing new from the application while others can struggle so much that they learn nothing.

On a scale from 1 to 5 where 1 was "strongly disagree," and 5 was "strongly agree," 37% answered 5 when asked if they felt engaged when using the application. 25% answered 4, 25% answered 3, 4% answered 2, and another 4% answered 1. The rest did not answer the question. The results are visualized in 19. From this, one can probably say that the way the application was design caused it to be engaging. An issue could be the novelty of using VR technology that could also add to the engagement.

4.3.3 Students of pedagogy at NTNU

Three students of pedagogy at NTNU tested the application at IMTEL VR-Lab while they were visiting. After testing, they answered a semi-structured interview whose answers were collected

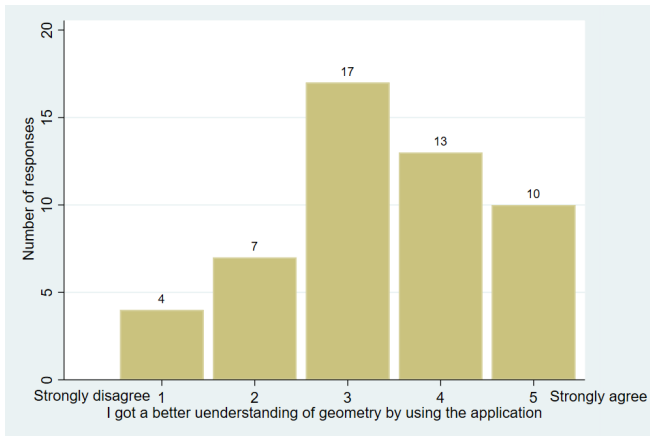


Figure 18: Students level of agreement to the statement: "I got a better understanding of geometry by using the application"

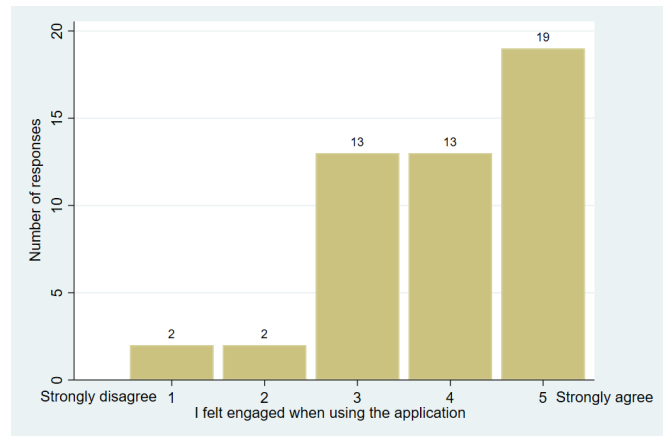


Figure 19: Students level of agreement to the statement: "I felt engaged when using the application"

by taking notes. The results are presented below, starting with what they meant was good. Then, continuing with what they thought was bad or could be better and ending with their thoughts on further development.

All three of the students liked the thought of using VR to visualize volumes and areas and giving the students a first-person experience of it. It could give students a more practical way to learn maths, which could be good, especially for students with difficulties. Two of the respondents also liked that users could play around with the objects in the environment. They believed that this would be fun for the students and that it was beneficial to let students play around more within the subject.

There where, however, many things the students thought could be better. An issue all the students had was understanding the task described in 4.2.2 where users were to create buildings. They did not think it was intuitive enough, and that the use of a laser to move the buildings was too different from the method used before. One also pointed out that the height of the flying platform might be too scary for some students. Feedback was also something they thought were lacking all three students agreed, especially in the form of sound. One stated that a positive sound like a fanfare as feedback could make the application more understandable and motivating. One also pointed out that sound, in general, could make the application feel more finished and make it more fun and engaging. Two of the students also mentioned that the overall application struggled with a connection through all the tasks and that some of it felt a bit pointless.

There were several suggestions when asking them about further development and what they would want to improve or add. As mentioned earlier, the addition of sound would significantly improve the application. The two students that thought the application felt somewhat pointless also stated that a story could bind the application together. A story would then give the user motivation and context

to why the tasks need to be done. One student also wanted hints in the application. However, it was mentioned that too many hints could affect how the student experimented with the tasks.

5 Phase 2

After an evaluation of the application, we decided that some major changes had to be done. This chapter will explain the decisions that were made and why they were made. Further, it will justify the design choices and present the results of the final evaluation.

5.1 Requirements

Before designing new tasks and changing the application, some new requirements had to be defined. These were based on the results from the evaluation of phase 1 and from gaining further understanding of the literature.

Initial requirements:

- 1. The application should have specific tasks to solve.**
Hiele's theory states that teachers should engage the students actively in exploring objects, see Section 2.3.2 about stages of learning. The application should take the role of the teacher and use tasks to actively engage the user.
- 2. The user should have access to all the information necessary to create the right concept image of the concept at hand.**
Hiele's theory also stated that teachers need to place ideas at students' disposal, see Section 2.3.2. The application in the role as the teacher needs to present all the information necessary. Without this information, students might end up creating the wrong concept image in the same way that figures can create the wrong concept image, see Section 2.3.1.
- 3. The application should give the user time to explore and reflect around the concept.**
Following phase 4 of Hiele's theory, the user should have free orientation and should reflect and elaborate on the problems and solutions, see Section 2.3.2.
- 4. The user should be able to physically interact with and perceive their environment to solve tasks, similar to real life.**
The ability to physically interact with objects supports immersion, as described in Section

2.1.3. Being immersed is also important for getting first-person experiences, as presented in section 2.4.

5. **Should have a tutorial to teach the controls and interactions used within the application.**
Not many users have much experience with VR and should get help figuring out the basic controller interaction.

Changed requirements:

6. **The application should use story and tasks that are puzzles as game element.**
Using game elements can motivate users, as presented in Section 2.2. Feedback from phase 1 supported the addition of a story and more game like tasks.

Additional requirements:

7. **The application should avoid making the user read to much.**
This requirement comes from user testing, where the users did not read and instead asked for instructions.
8. **The application should have a wide variety of tasks with different degrees of difficulty within the users skill level.**
Several of the students that tested the application noted that the tasks were too easy or too difficult. Some also mentioned that they wanted more different tasks at different skill levels. Not being good at math was also the second most mentioned reason for why students did not like maths.
9. **The application should give the user feedback when performing a task.**
Feedback is very important for learning in general, and the faster the user receives feedback, the better, see Section 2.3.3. Results from the expert and pedagogy student interviews, as seen in Section 4.3.1 and 4.3.3, also suggests that feedback is important enough to be its own requirement.
10. **The application should guide the user to their current task.**
Several students had trouble finding out where to go next when testing the application.
11. **The application should limit the use of instructions as not to provide an instructional sequence for the task.**
An instructional sequence limits the user's possibility to explore and discover the concept. This will take away some of the first-person experience of the user, as they will follow another persons thinking.
12. **The environment should contain intriguing visuals and visual effects.**
Having intriguing visuals and visual effects can immerse the user in the virtual world, and can motivate the users. Users also specifically requested more intriguing visuals, as described in the evaluation of phase 1.

User needs	Requirements
1. Easy to use	1, 4, 5, 7, 9, 10
2. Learn geometry	1, 2, 3, 4, 8, 9, 11
3. Learning differently than standard learning methods	3, 4, 6, 11
4. Motivation	4, 6, 9, 12

Table 4: User needs from Section 4.1.1 and their relation to the requirements

5.2 Development

The second development phase started with brainstorming ideas to make the application more exciting and motivating. A decision was made to move away from building a base, to a more unrealistic story with a mystery left from an ancient civilization. However, we wanted to keep the same mathematical concepts and tried to keep as much of the functionality that was already implemented. All the changes in this phase are done to fulfill the requirements set in Section 5.1 and will be explained in more detail below.

5.2.1 Changes

Several changes had to be done to fulfill the new requirements. These changes were based on previous experience from phase 1 and some new theories. Some of the changes were bigger than others, and new logic and assets had to be made.

Tasks

Based on the results, we decided to drop the learning space altogether and rather focus on one environment. The observation was made that most users did not remember or think about what they did in the learning space when performing tasks in the task space. By merging the learning space into the task space, the connection between the concepts and the tasks improved. Both the learning and the task space gave an instructional sequence for the task. To avoid this, new tasks were created that were based on the old ones. These new tasks will be described in detail in Section 5.2.2 and Section 5.2.3.

Audio

It was decided that audio was needed in the application. Results from all sources in the evaluation of phase 1 suggested this. Adding audio was planned from the start, but it was not prioritized over other features. The audio was mainly used as feedback for the tasks but also used for way-finding

aid. The audio used for way-finding is spatialized, meaning that audio is perceived to come from a direction. The tablet that is described later in this section also uses spatialized audio to present its information.

Story

The story was changed to make the application more interesting and exciting. The new story puts the users in the center where they are put in the role of a space agent that needs to figure out the mystery behind artifacts left by an ancient civilization. The users need to solve a puzzle to unlock the next artifact. Messages to immerse the player in the story will be sent upon the completion of a puzzle. When the user has solved the last puzzle, they will find water, which is essential for their survival on Mars.

Tablet

A tablet was implemented as a way to guide the user through the world and at the same time, provide the user with the story. The tablet receives audio messages from "ground control," and hints if needed. The user can ask for hints by pushing a button (see Figure 20); these hints will be delivered as messages on the tablet. The tablet displays the messages in text-bubbles, which can be scrolled through to read older messages. To scroll the user simply touches the tablet and moves their hand up or down like an ordinary tablet or phone. All the messages are read out loud, so the user does not have to read as much but still has the option to do so.

The tablet hovers in the air so the users can put it where they want, without it falling to the ground. If the user goes too far away from the tablet, the tablet will follow the user. A tablet is something most people are familiar with and know how to use, which signifies how to use it.

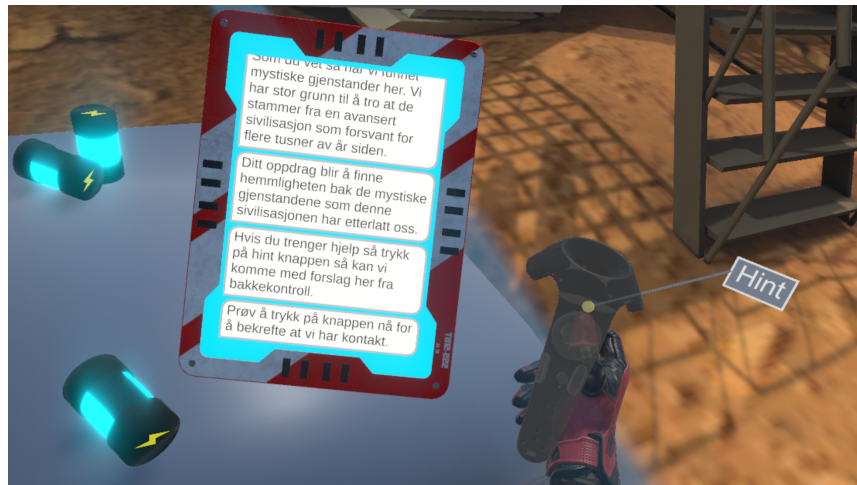


Figure 20: Tablet from the application

Waypoint

Several users had problems with figuring out where to go next, and thus, the application needs a way to draw the users attention towards the point of interest. The application uses added a light beam at the point of interest as a wayfinding method. This is something that stands out in the environment and guides the user, as mentioned in Section 2.1.4. Spatialized audio that played when a new task appeared was also added to supplement the visual wayfinding method.

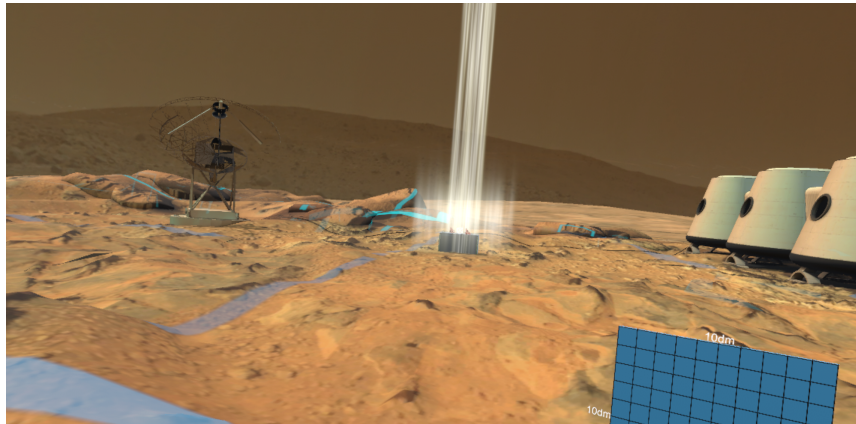
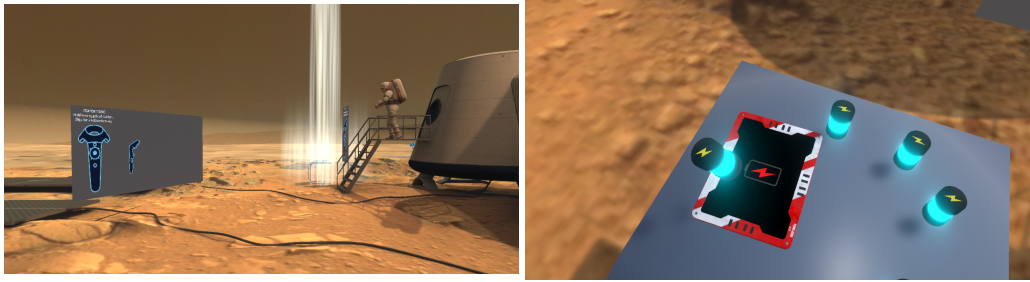


Figure 21: Waypoint from the application

Tutorial

In the first version of the application, there was a series of infographics explaining the different buttons on the controller. For the new version, a mandatory tutorial process was created. Here the user needs to teleport to a location and charge a tablet. The application uses animated info-graphics to explain how to teleport, and an ordinary info-graphic to show how to pick up items. In order to progress, the user needs to teleport to the tablet, pick up a battery, and place the battery on the tablet. The tablet creates a noise to direct the user's attention and displays a blinking battery symbol (see Figure 22). Both the battery and tablet contains the same symbol to map these two objects together. This tutorial should cover all the basic controllers the user will need in the application.



a: Animated infographics and waypoint

b: Charging the tablet

Figure 22: The new tutorial

5.2.2 New area and volume task

The learning objectives of this task are to explore the concept of volumes and areas and the relationship between their measurement units. The didactician of mathematics mentioned that we should look more into conversion between measurements. This task is designed to have several solution paths and to encourage the user to reflect and elaborate on the problem, and thus following phase four of Hiele's theory described in Section 2.3.2. The user is provided with all the information necessary to perform the task to satisfy requirement 2.

This task is designed as a puzzle where the user has to figure out what to do. Certain clues indicate what the user needs to do, such as a finished example and a whiteboard with info about conversion between measurement units (see Figure 23). If the user cannot figure out what to do, they can ask for hints, which explains the task in more detail. The task consists of five different parts, one table with four plateaus and four platforms, as seen in Figure 24. Both the plateaus and platforms have the same markings which are mapping them together, and in addition, a cable connects each plateau to a platform.

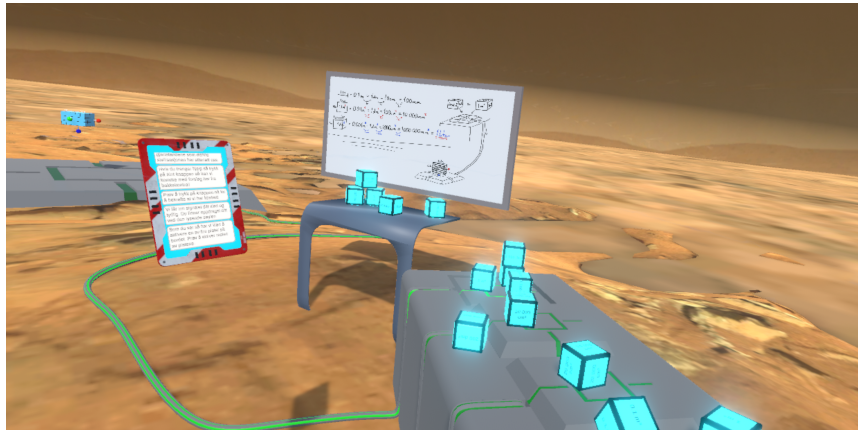
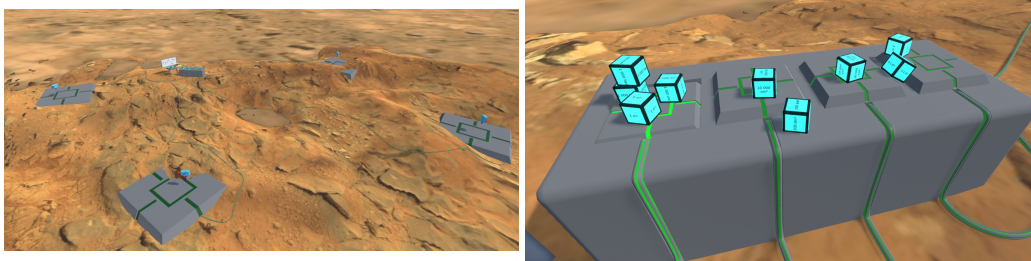


Figure 23: Overview of categorizing task

There are several cubes with a value on that are glowing to give it a more futuristic look. The cubes are quite small, and they are the only objects which are not attached to anything which gives them the affordance to be picked up. One problem with small items that can be picked up is that they often also affords being thrown. To avoid losing a cube due to this, the cube will teleport back to its original position if further than five meters away from its original position.



a: Overview of the platforms and table

b: Overview of the table

Figure 24: Overview of task 1

The user's goal for this task is to categorize the different cubes on the four different plateaus on the table. The cubes that go together are those with the value that represents the same volume or area; for example, $1000dm^3$ belongs together with $1m^3$. The user will get instant feedback when all the cubes that belong together are placed on a plateau. The plateau will start to glow and slowly sink a bit down, which gives the user visual feedback, but it will also play a sound to provide auditory feedback. Simultaneously as this happens, the cable that connects the plateau with a platform will start to blink, to indicate that the cable should be followed. At the platforms, there will be either a rectangular plane or a rectangular prism, depending on which value lie on the platform. They

have two or three levers, depending on it being a plane or a prism. These are used to change the size of the prism or plane by dragging them in their respective directions. The user then needs to change the volume/area of the prism/plane to what the cubes on the plateau specify. In Figure 25, the values on the plateau are equivalent to $1m^3$ and thus rendering the platform correct when the prism has a volume of $1m^3$. The platform will also give a visual and auditory feedback when completed.

After all the cubes have been categorized, and all the platforms are solved, the application will move on to the next task. The new task will emerge from the ground creating clouds of dust to draw the users attention. This will also progress the story and trigger a new dialogue that guides the user further.

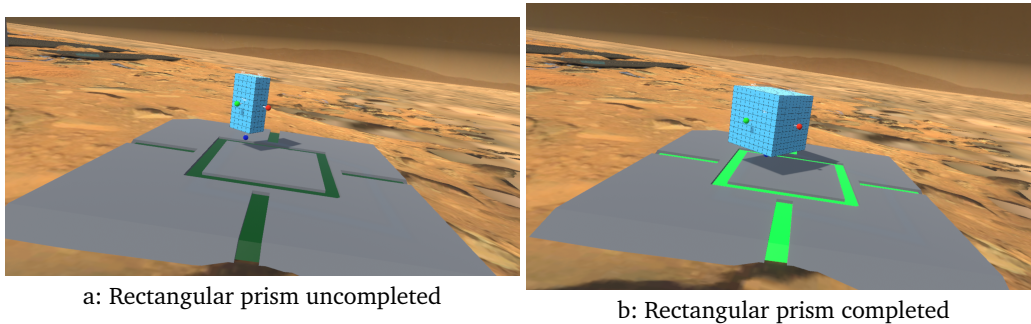


Figure 25: Manipulating volume task

5.2.3 New pyramid volume task

The learning objective for this task is to explore the concept of pyramids and their volume. This task is designed to follow phase 2 of Hiele's theory (see Section 2.3.2), where the user can explore the pyramid and how they can be put together to form a cube. The user will be encouraged to reflect on this to find the connection between the volume of a cube and a pyramid. The user has all the information necessary to solve this task through reflection, but hints are also available.

This task consists of two different parts. In the first part, the user needs to build a cube from three equal pyramids. The pyramids have a patterned texture to make their shapes more perceivable for the user (see Figure 26). The cube needs to be built at the center of a table, which is indicated by a square and an outline of a cube. In addition, a transparent pyramid will be shown when one of the pyramids is picked up, to indicate further what to do with them. To solve the puzzle, all the pyramids needed to be placed inside the cube. If the user places a pyramid wrong, they will get instant feedback that something is wrong. When the cube is built, the table will give both visual and auditory feedback. To keep it consistent with the previous task, the green pattern will start to glow, and the same sound as in the other tasks will play. In addition, a new pyramid will spawn, which starts part two of the task when picked up.

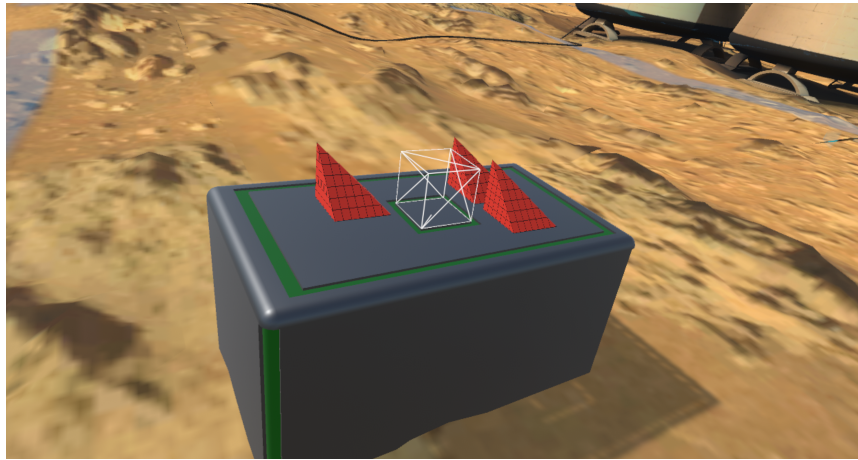
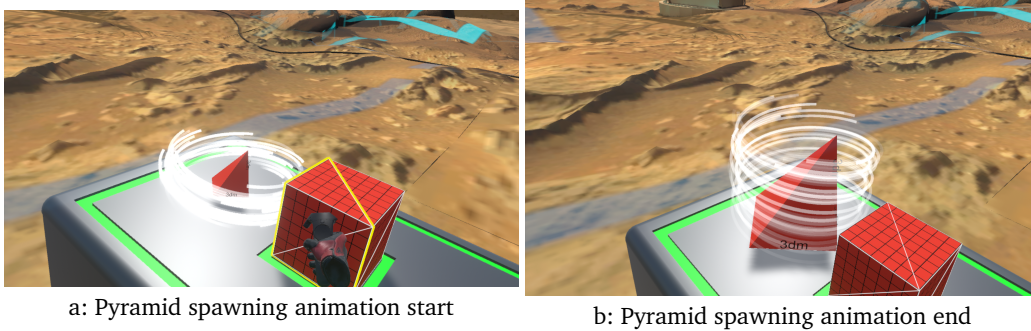


Figure 26: Pyramid puzzle



a: Pyramid spawning animation start

b: Pyramid spawning animation end

Figure 27: Pyramid spawning

The second part of the task consists of four pyramids and four pillars. The pillars will emerge from the ground, and three pyramids will spawn on the table when the user picks up the new pyramid. The pillars have the same pattern as the platforms and plateaus in the previous task to keep things consistent. Each pillar has a value connected to them, which is shown as text at the top of the pillar. The objective is for the user to find the pyramid with the same volume as the pillars value and place the pyramid on that pillar. When a pyramid is picked up, transparent pyramids will spawn over the pyramids to indicate what to do with them. When a pyramid is placed on a pillar, the pillars pattern will start to glow white. This is important feedback that tells the user that the pyramid is registered. First, when all the pyramids are placed correctly, the task will be solved, and the pillars will glow green. The reason for not letting the user instantly know if the pyramid is placed correctly is that they could solve the task through trial and error, not reflecting over their choices.

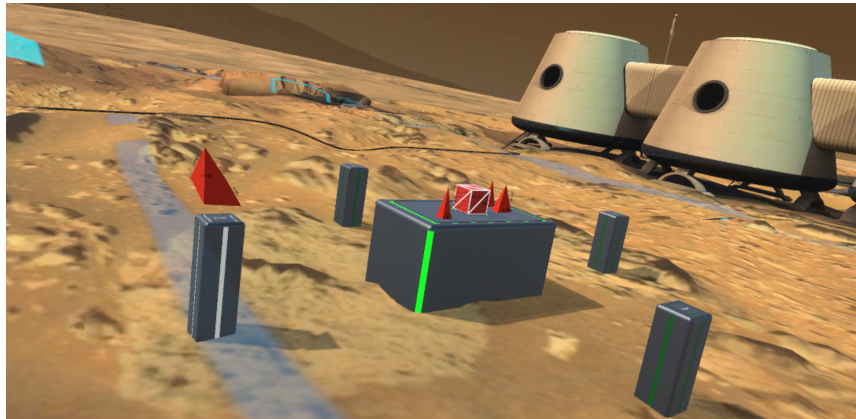


Figure 28: Placing pyramids on pillars

5.3 Final evaluation

The final evaluation was done by testing the application with students from a local high school, an expert in didactics of mathematics, an expert in serious games and teachers at the NKUL 2019 conference. The high school students answered a pre- and post-test questionnaire, the experts answered a semi-structured interview, and the teachers at NKUL answered a short questionnaire. In addition, observations were gathered when testing on some of the high school students.

5.3.1 High school students

The application was tested on 15 high school students for the final evaluation. The tests were conducted in the school's own VR-lab equipped with Oculus Rifts. Even though the application was mainly developed for the HTC Vive, the practical reasons outweighed the potential small differences this would have. The main issue would be tracking when the person faces away from the sensors.

The tests were conducted two to four at the time with us and one teacher present. Our role would be to introduce the students to what they would do, to keep quiet and observe and only help if the students asked for it. The teacher's presence was mostly due to the school's own interest in VR. First, the students conducted a pre-test questionnaire, then they tested the application, and finally, they answered a post-test questionnaire. The questionnaires were reviewed by the teachers at the high school before the tests were conducted and small changes were made.

During testing questions in the questionnaires were written in Norwegian. The questions have been translated when presented in this section. The results of this test will be presented below. The original questionnaire can be seen in Appendix A.3

Familiarity with VR and technology

All but one person in the test group answered that they had tried VR before, as shown in Figure 29. This means that most of them were familiar with at least the possibility of moving their head and turning around. From conversations with their teachers, many of the students had tried VR at the school. However, the type of VR application they would have tried varies from seated 360 documentaries to VR games with controllers more similar to our application. 67% of the students also answered, "agree" or "strongly agree" to the question on their self-efficacy in learning new technology, seen in Figure 30. Only 13% disagreed or strongly disagreed to the same statement; therefore, these testers might be better at understanding and using VR technology than the average high school student. Student's interest in video games is spread evenly across the scale, as seen in Figure 31.

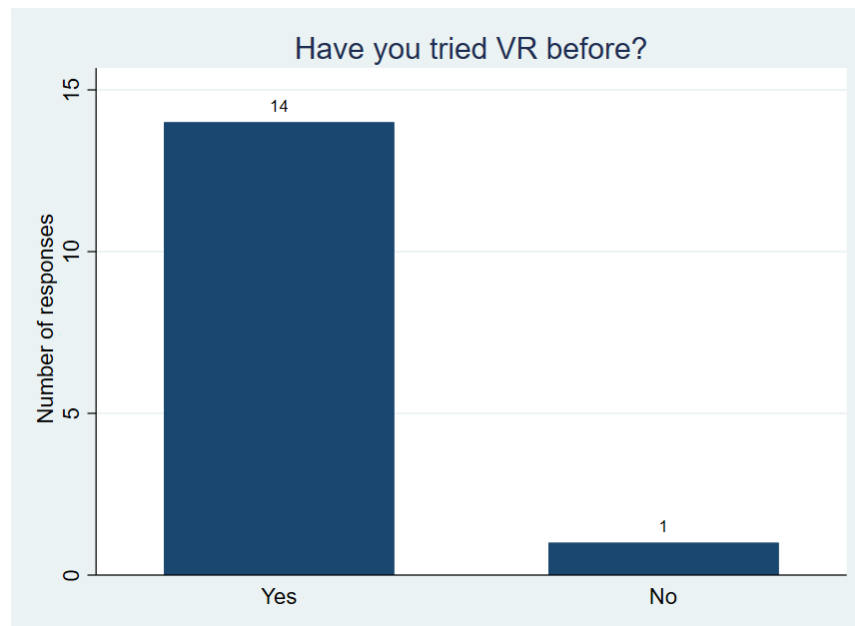


Figure 29: Students answers to "Have you tried VR before?"

The students were also very positive in their belief that VR could be used for learning, as seen in Figure 33. 93% of students agreed or strongly agreed when asked if they believed that VR could be good for learning, while 7% strongly disagreed. In Figure 32, we see that 87% of students agreed or strongly agreed when asked if they thought VR could be used to learn geometry, while 7% strongly disagreed. The rest did not answer the question. This shows a high positive attitude towards VR, and the group might, therefore, be biased towards the use of VR for learning.

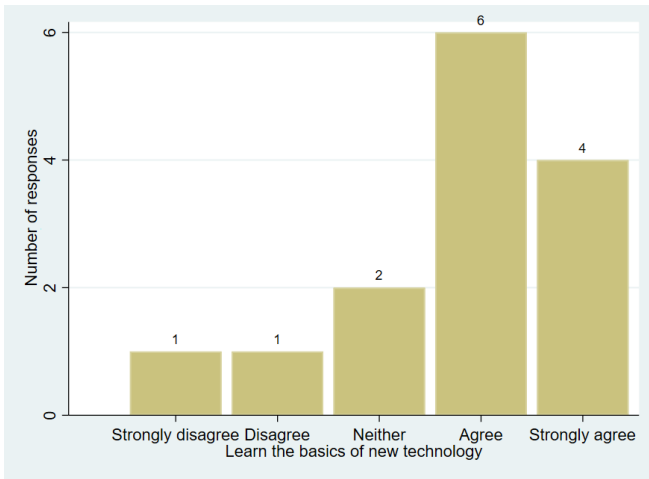


Figure 30: Students self-efficacy on their ability to learn the basics of new technology

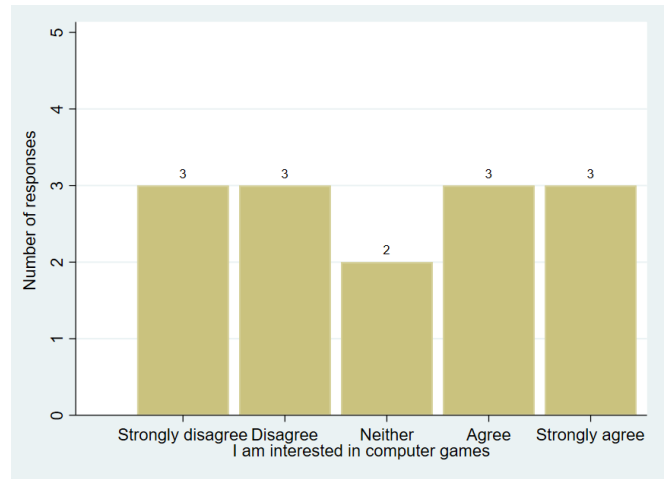


Figure 31: Students level of agreement to the statement: I am interested in computer games

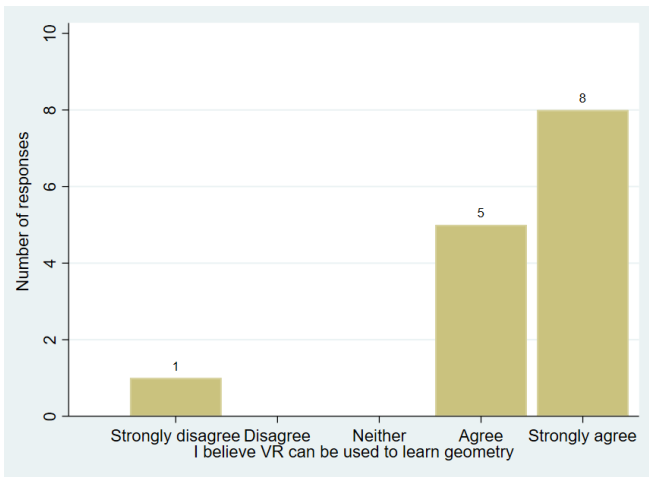


Figure 32: Students level of agreement to the statement: I believe VR can be good for learning geometry

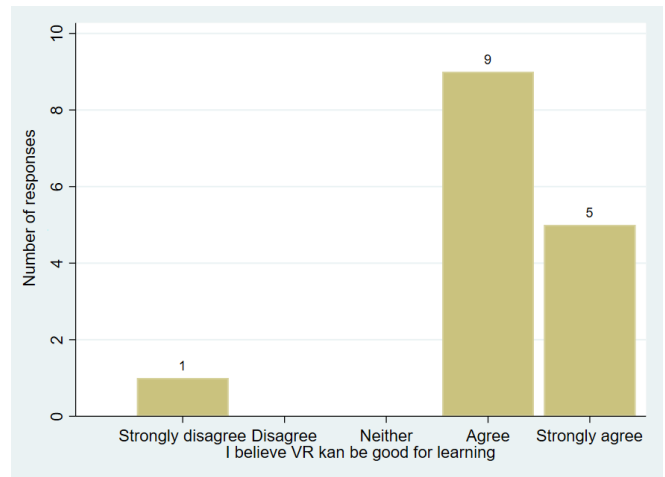


Figure 33: Students level of agreement to the statement: I believe VR can be good for learning

Effects on motivation

When it comes to motivation, the application shows some positive results. The self-reported motivation of students testing the application is higher than their motivation in the classroom. The difference between the pre and post answers are statistically significant, with a probability of error (p) equal to 4.9%. The difference is clear by looking at the graph below, see Figure 34. 40% of students answered agree or strongly agree on if they felt motivated in a regular class about geometry, while 73% did the same when asked if they felt motivated to complete the tasks given in the application. This is an increase of 83%. 60% of students answered disagree or strongly disagree when asked about their motivation in the classroom, while only 13% answered the same about the VR application.

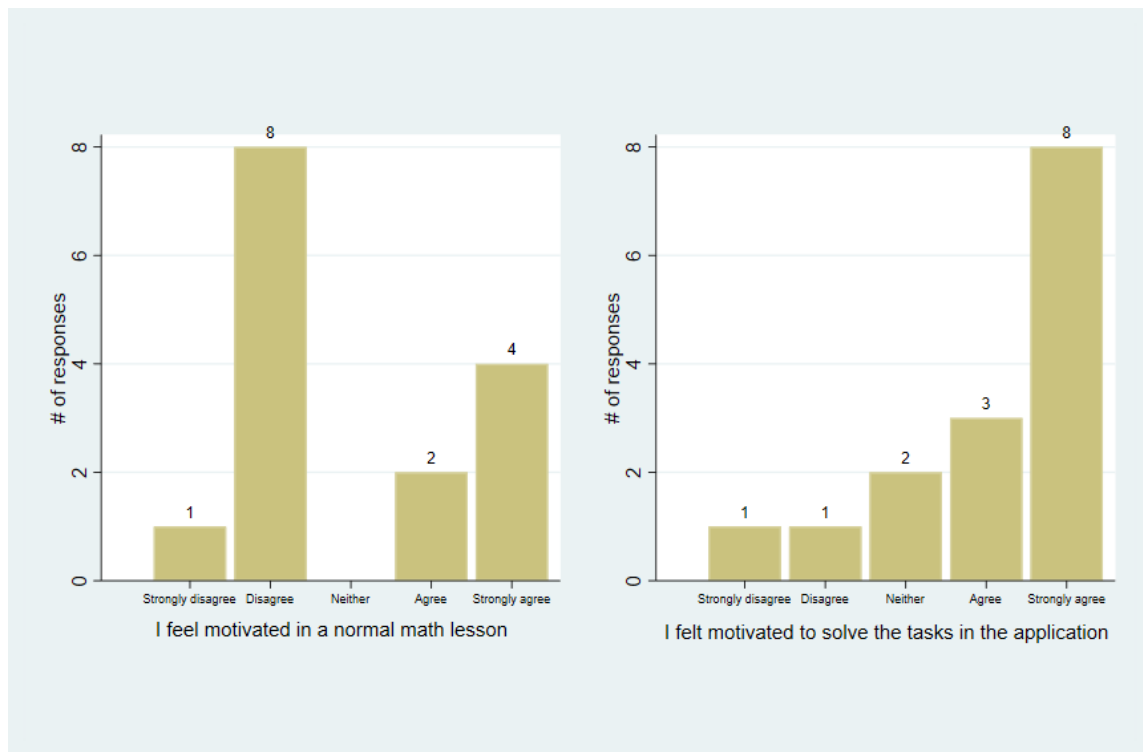


Figure 34: Students level of agreement to statements on their motivation in a normal math lesson (left) and in the VR application (right)

Effects on Focus

The students reported their self-efficacy for their ability to focus in class. The results showed that 40% either disagreed or strongly disagreed to if they were confident in that they could keep focused during a class about geometry, see Figure 35. 53% either agreed or strongly agreed to the same

question, however only 13% of these strongly agreed. On the students self-efficacy for keeping focus in the VR application, only one student, or 7%, answered strongly disagree, while none answered disagree. 86% of the students answered, agree, or strongly agree, where 60% of students strongly agreed. The difference was statistically significant, with $p=0.55\%$.

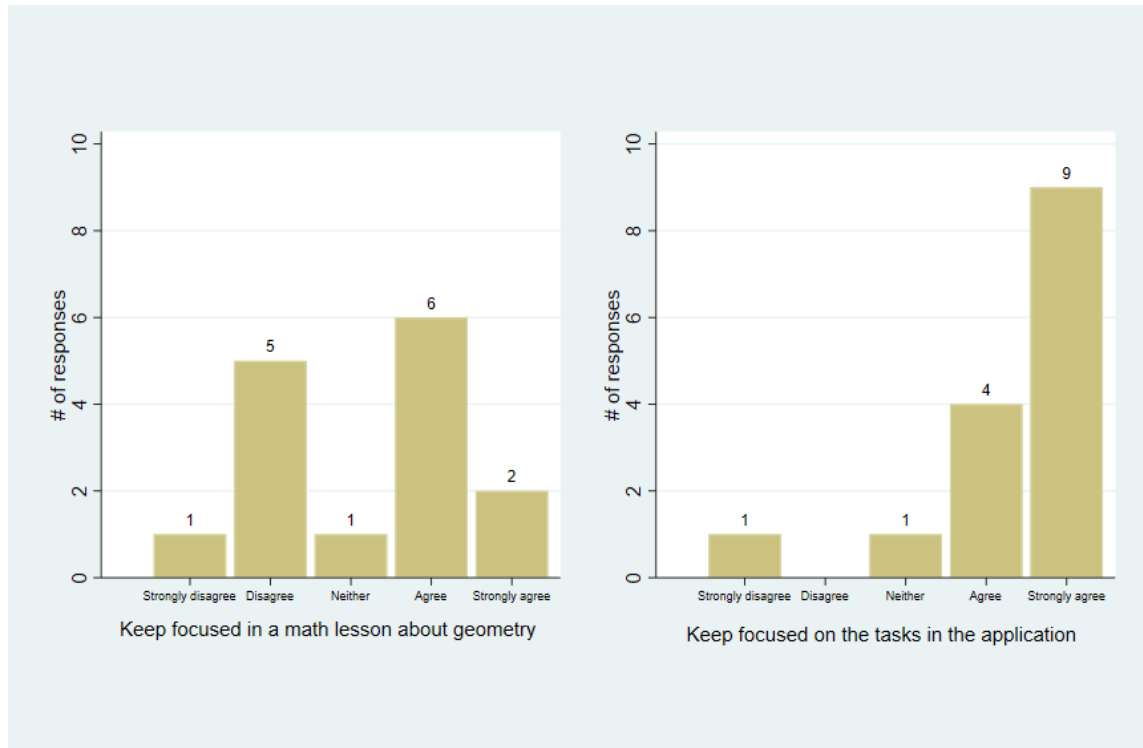


Figure 35: Students self-efficacy on their ability to keep focused math lesson about geometry (left) and in the VR application (right)

Effects on understanding

The test itself seems to have had little effect on the students' self-efficacy of solving geometric tasks from their curriculum. There was no significant change between the answers in the pre and post-test, as seen in Figure 36. Most of the students, however, reported that the application gave them a better understanding of the mathematical topics presented. The students were asked if they agreed that they had gotten a better understanding of the three topics: area of rectangles, volume of rectangular prisms, and volume of pyramids. The results can be seen in Figure 37.

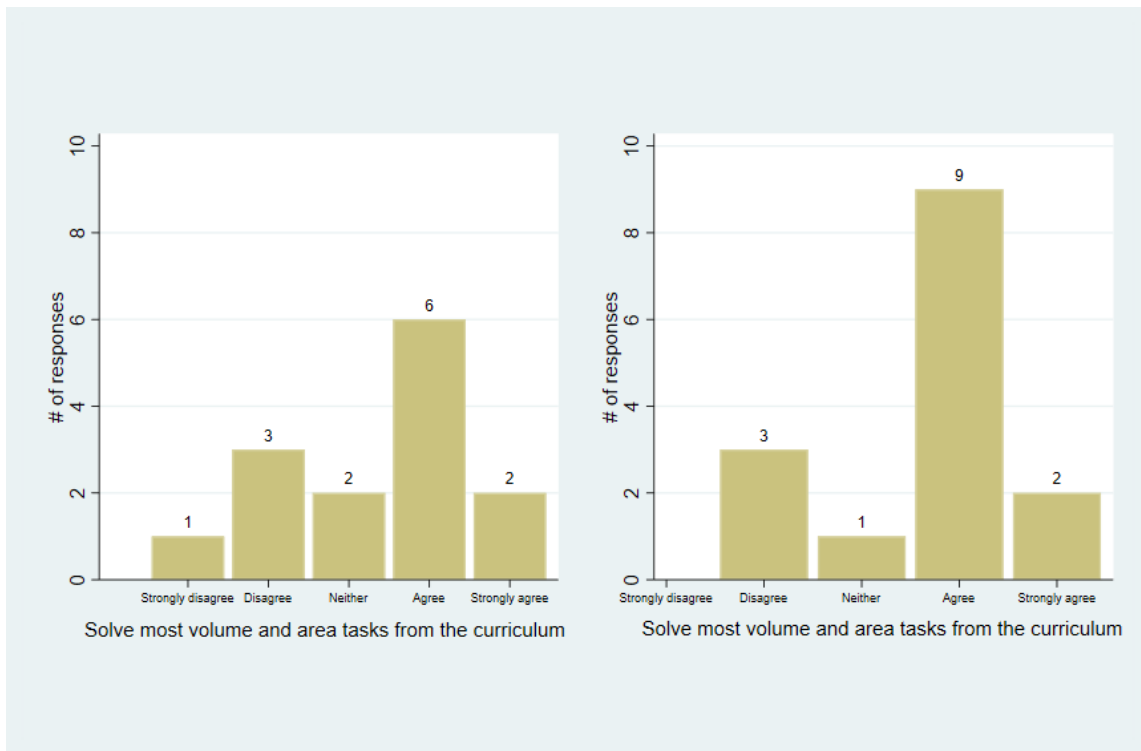


Figure 36: Students self-efficacy on their ability to solve most tasks from the curriculum during the pre (left) and post (right) test questionnaire

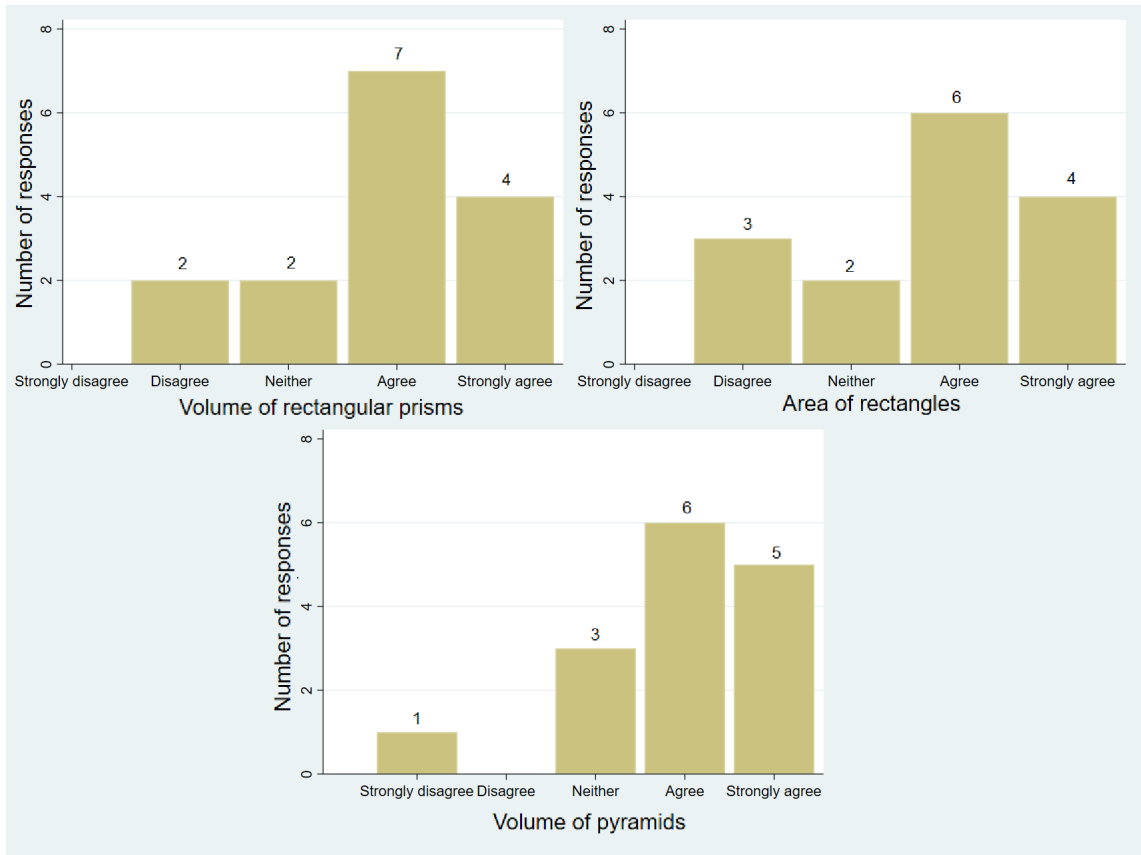


Figure 37: Students level of agreement to statements if by using the application they got a better understanding of the volume of rectangles (top left), the area of rectangles (top right) and the volume of pyramids (bottom).

Students answered on their ability to get a better understanding of geometry in a classroom setting vs. in VR. As seen in Figure 38, most students agree that they will be able to increase their understanding in either case; 64% in a classroom setting and 79% in VR. However, there is a notable increase in students strongly agreeing in the case of VR. Only 14% strongly agree in the classroom case in contrast to the 50% that strongly agree in the VR case.

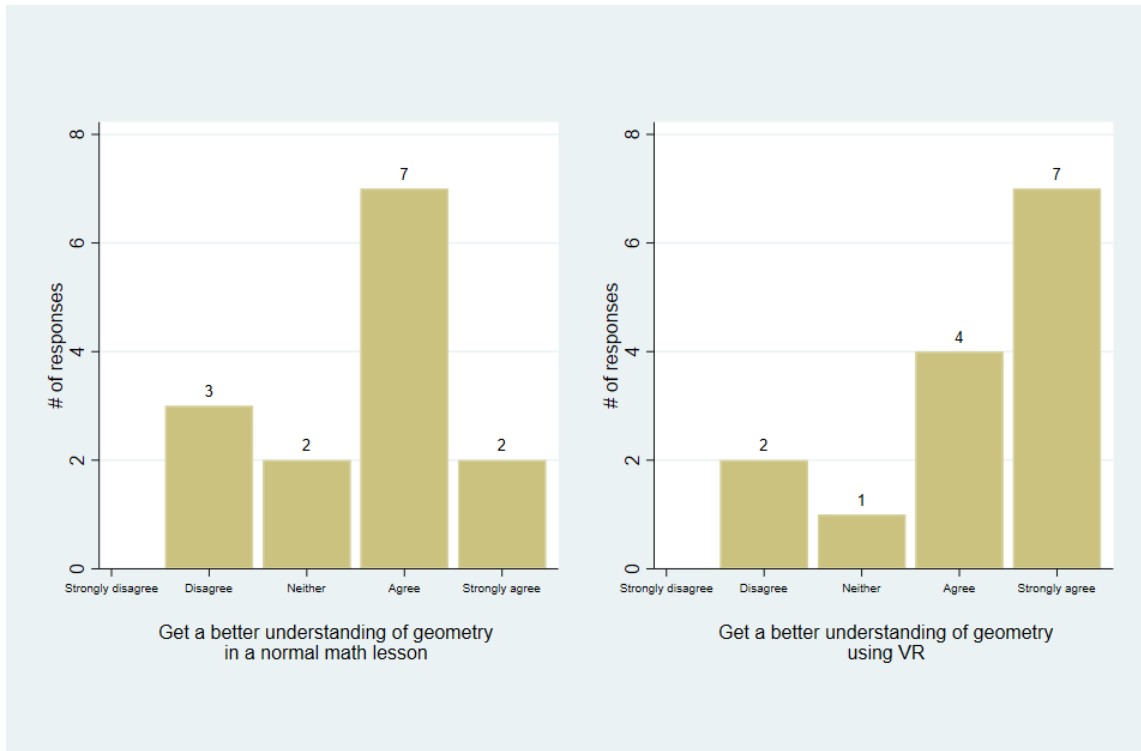


Figure 38: Students self-efficacy on their ability to get a better understanding of geometry in a normal math lesson (left) and in the VR application (right)

Effects on mathematical anxiety

54% of students reported that they could feel tension or apprehension during a math class about geometry. see Figure 39. Only 15% disagreed or strongly disagreed to this. Asking students if they felt tension or apprehension while solving the math tasks in VR gave completely different results. Now only 20% of the students agreed or strongly agreed while 67% disagreed or strongly disagreed. 50% of the students answered agree or strongly agree to that they could feel "stupid" when having problems with math, while 33% of students could feel the same in the VR application, see Figure 40.

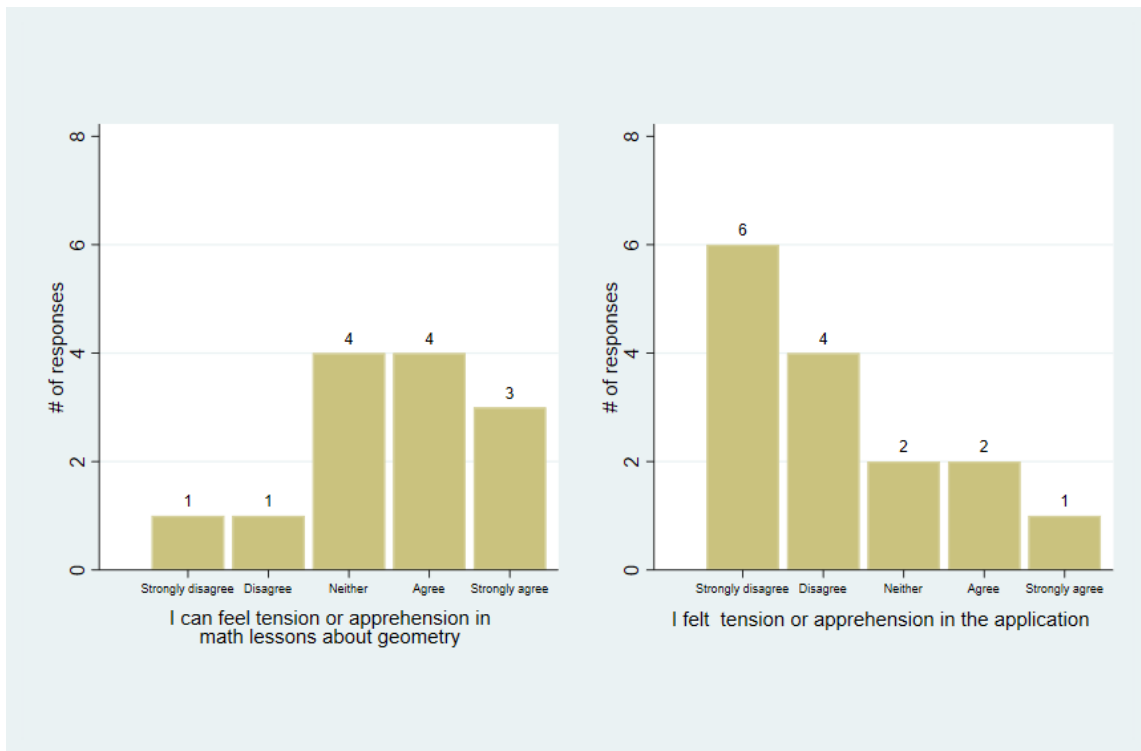


Figure 39: Students level of agreement to statements on their feeling of tension or apprehension in a normal math lesson about geometry (left) and in the VR application (right)

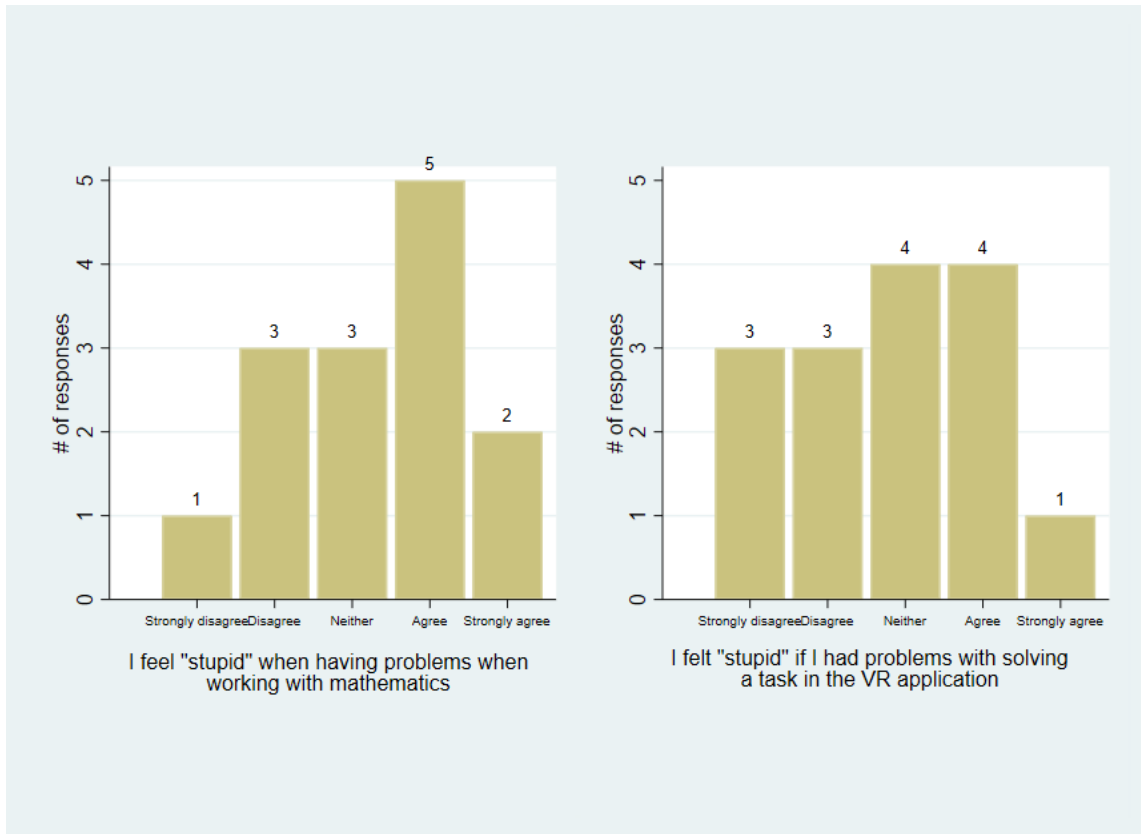


Figure 40: Students level of agreement to statements on if they feel "stupid" when having problems working with mathematics (left) and in the VR application (right)

Users experience

Students were in general positive when giving feedback on the environment and sounds of the game. When asked if the sounds in the game made it engaging to solve the tasks all, but one tester answered agree or strongly agree 42. 87% agreed or strongly agreed that the environment was interesting while the other 13% disagreed or strongly disagreed 43. 67% answered "No," seen in 41, when asked if they would prefer to solve the tasks without the story and in a more neutral environment, 27% answered "Yes" and the rest did not answer. The students then answered a question on why they answered yes or no. The students that answered "No" stated reasons stating that it was motivating and fun. None of the students answering "Yes," gave any reason for their choice. Most of the students' reasons were that the story and environment added fun, engagement, or motivation to the application. Two students also wanted more and different stories and environments.

Some of the testers struggled a bit with learning the controls and understanding what to do at times. 73% of the testers agreed or strongly agreed that it was easy to understand what to do, while 20%

disagreed 44. 53% answered agree or strongly agree on if they could use the application intuitively without help. 27% answered disagree or strongly disagree to the same question 45. Students did, however, typically not struggle with knowing when they had finished a task or figuring out where they were to go 46 47. 60% of students did not think the tasks were too difficult, 27% answered neither agree or disagree, and 13% answers agree or strongly agree, as seen in Figure 48.

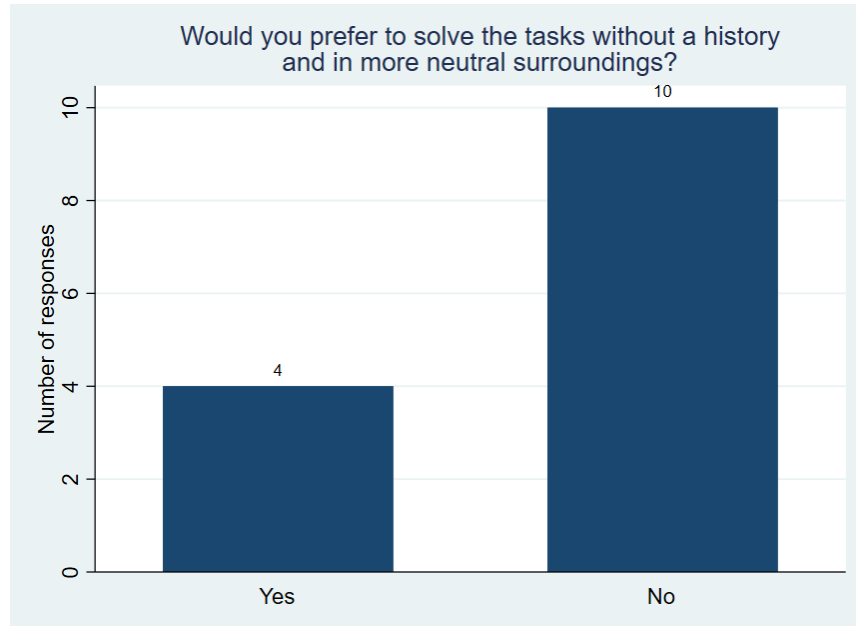


Figure 41: Would you prefer to solve the tasks without a history and in more neutral surroundings?

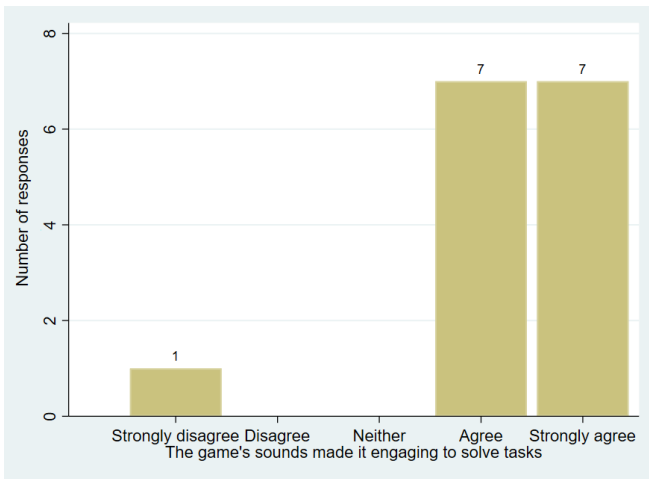


Figure 42: Students level of agreement to the statement: The game's sounds made it more engaging to solve tasks

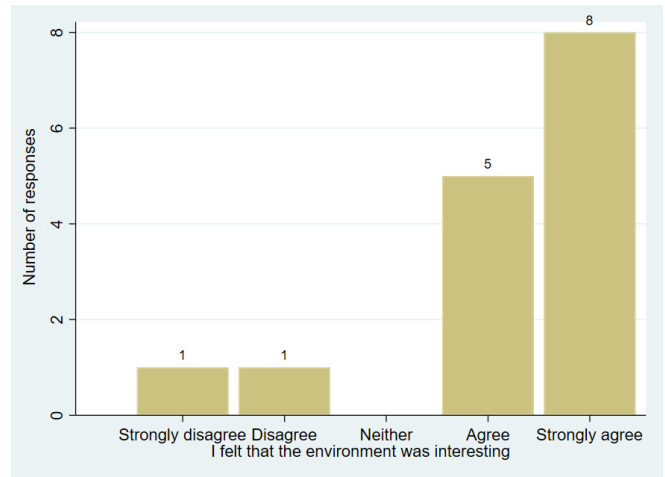


Figure 43: Students level of agreement to the statement: I felt the environment was interesting

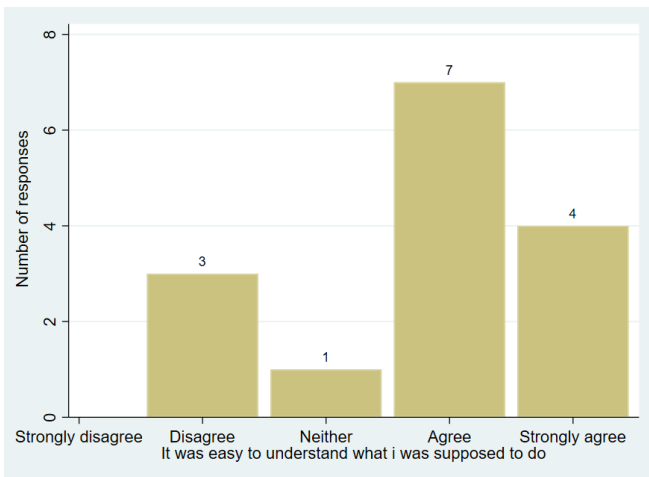


Figure 44: Students level of agreement to the statement: It was easy to understand what I was supposed to do

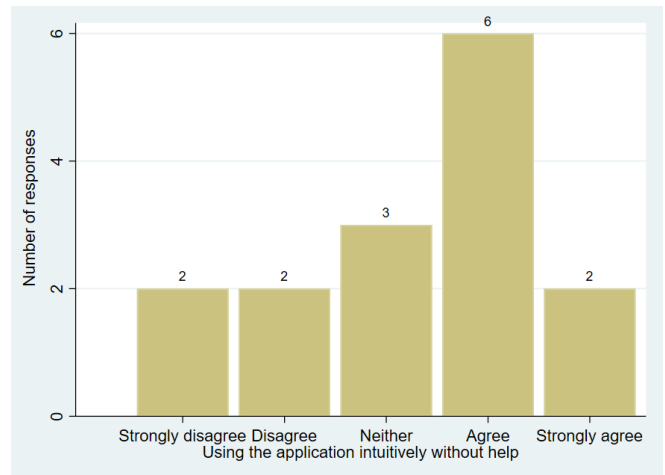


Figure 45: Students self-efficacy on their ability to use the application intuitively without help

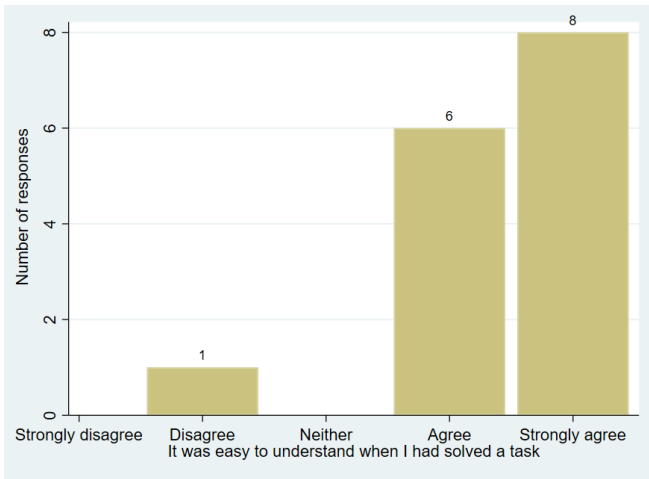


Figure 46: Students level of agreement to the statement: It was easy to understand when I had solved a task

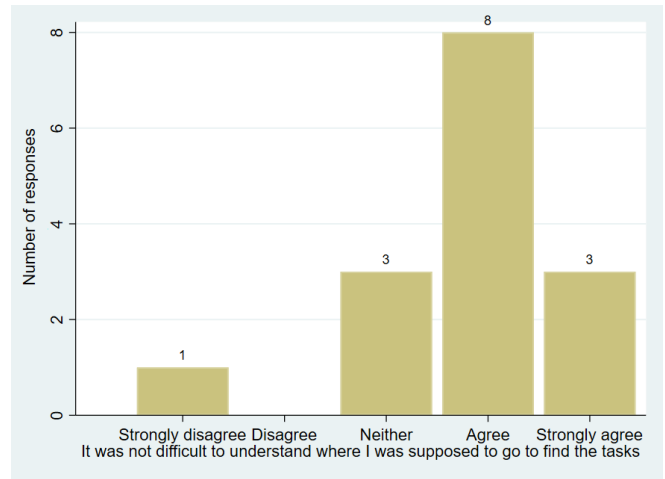


Figure 47: Students level of agreement to the statement: It was not difficult to understand where I was supposed to go to find the tasks

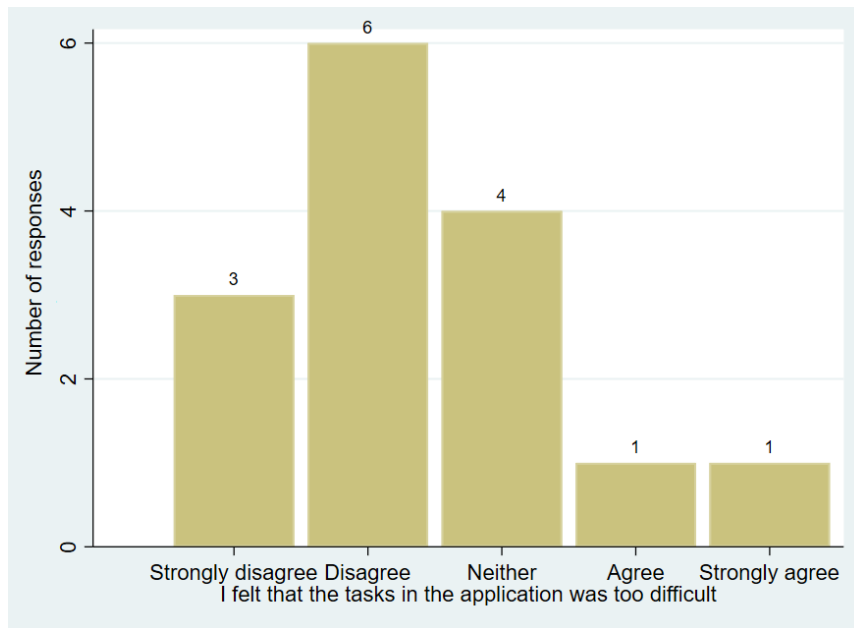


Figure 48: Students level of agreement to the statement: I felt that the tasks in the application were too difficult

Differences in gender

There was two significant differences between genders found from the questionnaire. The first was that women had a higher tendency to feel "stupid" when struggling with a task in the VR application, see Figure 49. 44% of women agreed or strongly agreed that they felt "stupid" when struggling with a task in contrast to the 17% of males that did the same. This difference was statistically significant, with $p=1.8\%$. Women also felt that the environment was more interesting than what males felt, see Figure 50. All women answered agree or strongly agree on if they thought the environment was interesting, while 67% of males did the same. The rest of the males disagreed or strongly disagreed to the same question. This result was also statistically significant, with $p=1.5\%$.

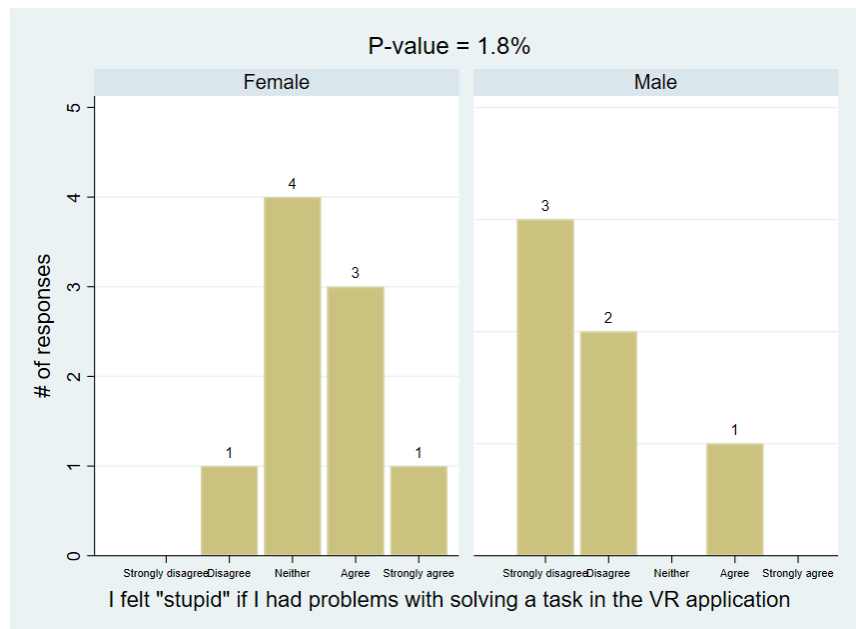


Figure 49: The difference in female (left) and male (right) responses on their level of agreement to if they could feel "stupid" in the VR application

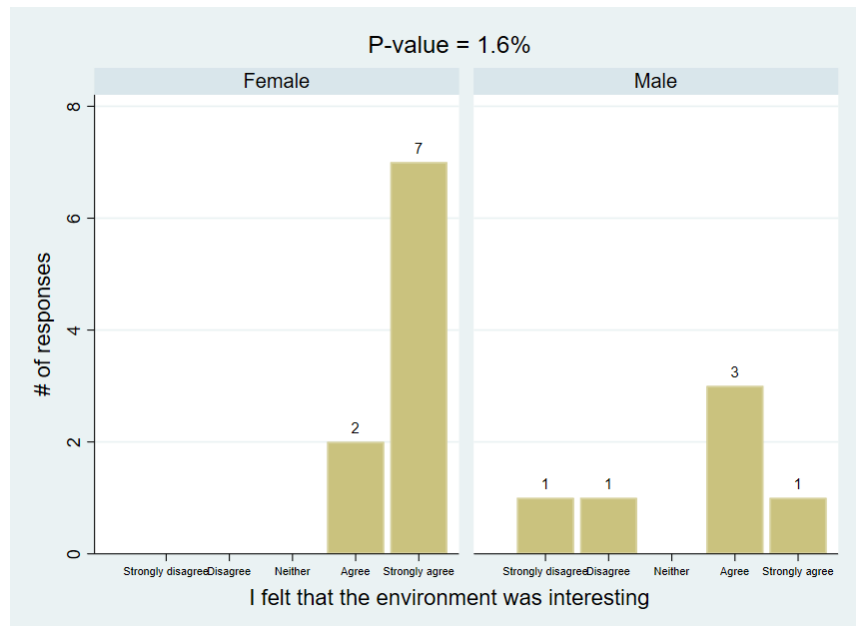


Figure 50: The difference in female (left) and male (right) responses on their level of agreement to if they felt the environment was interesting

Observations

Observations were made during the tests, and some key observations will be presented here. Many of the students did ask for help with tasks during the test. This was mostly due to some misunderstandings in the first task and not so much about the mathematical problems themselves. However, some students did also ask for help with the mathematical problems, especially if they already had asked for help.

Some students had problems with creating the right volume when dragging the rectangular prisms. When this happened, many started counting the cubes and rectangles. Some of these did not understand that the cubes inside the prisms had to be counted and gave up on figuring out the volume/area themselves. They ended up asking for help. However, a few of these students managed to make the connection and eventually solve the task.

Some students experimented with different ways to create volumes. One tried to make a prism with a volume of $1m^3$ by making the length of two sides $1dm$ and one side $1000dm$. The student was disappointed when they found out that the lengths were limited to $20dm$. Many of the students also had to take a step back several times to look at the prisms at different angles before they continued with the task.

5.3.2 Expert in didactics of mathematics

During the final evaluation, a test was conducted with the same expert in didactics of mathematics as in the evaluation of Phase 1. The expert tested the application and answered a semi-structured interview that was recorded and reviewed afterward. The expert's thoughts on the application's strengths and weaknesses will be presented below.

Strengths

One of the biggest strengths of the application from the expert's point of view was that the virtual objects with measurements were the same size in the virtual environment as in real life. This is something that might be difficult to do in real life, especially for big sizes such as $1m^3$ and more. The expert also mentioned that such spatial understanding is important, both for, real-life scenarios, such as understanding the size of a room by using square meters, and for more advanced math and science subjects. Another strength of the application was the manipulation of the rectangular prisms by dragging. In this task, one can explore more than in the others and solve the task in different ways.

The use of a history as motivation was something the expert liked. This, together with the explorable environment, made the application seem like a game that would be motivating for many students. The use of new technology such as VR could also in itself be motivating. The expert also liked the addition of a tutorial, as problems with using the application could be negative for the experience.

Weaknesses

The biggest weakness the expert mentioned was the problem of noise. The noise here being distractions in the environment and tasks. The first example mentioned was the first task, as described in Section 5.2.2. Here the cubes on the table with measurements on them was distracting in themselves because they were geometric shapes. Someone could think that one of these cubes were the size equal to the number on them. The cube shape could also make the user think that they were meant to be stacked, and all this could add noise to the task. Also, the size of the rectangular prisms in the first task could add some noise. This was due to issues with getting an overview of the full shape while interacting with it. In the second task, as described in Section 5.2.3, noise could come from the task of locating the correct pillar while calculating the volume of the pyramid. The expert mentioned that this did not have to be negative and that some might be fine with doing both at the same time. It was, however, something to think about when creating tasks.

The second task was also the task with the least clear learning outcome. Showing students that a cube is dividable into three pyramids is a good learning outcome, but it would most likely not become clear to students from the application alone. Typically to achieve this type of realization, teachers talk to the students afterwards. Another weakness the expert mentioned was that there would always be some students demotivated by using technology like VR. The interest in games is

also probably varying in students and could affect motivation. The expert did, however, believe that this would motivate more students than not.

Recommendations for further development

When asked what the expert would change or fix the first thing mentioned was to fix the second task about building the cube from pyramids. By animating the cube splitting up before users are to put it back together could make it easier to understand the learning outcome. Also, by repeating the task for different sized cubes and also by adding the formula in a smart interactive way could also be beneficial. The expert believed in the motivational benefit of using stories, but mentioned the difficulty of making a good story that motivates and also focuses on the learning outcomes. This is something that could be looked more into in the future.

Other types of tasks the expert would like were looking into the volumes of several other shapes and also the visual proofs of the shapes' formulas. They also mentioned adding more experimental tasks where one changes certain parameters of an object and observes the changes made. Using water to show volume, explaining Pythagoras's theorem and visualizing integration are other things mentioned.

Lastly, the expert looked at the list of requirements created for the application. The requirements were described as being "difficult to disagree with" and "good general requirements for such an application." The expert suggested that a requirement for experimentation in tasks could, however, be an excellent addition, since it is known that many can learn more from experimentation.

5.3.3 Expert in serious games

During one of the IMTEL Innovation Days, we conducted a semi-structured interview with an expert in serious games. This test and interview was conducted at the IMTEL VR-Lab, where the expert was trying the application on an HTC Vive. The expert did not speak Norwegian and therefore, could not understand the verbal and written information in the game.

The questions asked were mainly focused on the game elements and tasks in the application, but all types of feedback were welcome. The difficulty of developing serious games for education was also discussed.

The first thing the expert notices was the lack of connection between the story and the learning outcome, geometry. However, this changed when we explained the story and that we were going for a mystery puzzle type of experience. Now the connection between geometry and story was that one had to solve some puzzles that were based on geometry. The expert liked the mechanics of picking up, putting down and dragging objects since it was intuitive and easy to do.

The issue of the cubes in task one that was brought up in the previous section was also brought up in this interview. The expert stated that it might be confusing because one might believe that the

measurement written on the cubes are the measurements of the object. This was confusing when all the cubes looked the same size, and some had 2D measurements on them. A possible solution could be using slots in the table to put the cubes in instead.

Most of the feedback in the game was also good. The sound and lights that were activated when a task was finished was easy to understand and gave immediate feedback. However, In the last task that was described in Section 5.2.3, the lights turn white when the pyramids first are placed on the columns. This feedback could be confusing the expert stated and suggested to not give this feedback at all and only when all the pyramids were added correctly. After this, we started a discussion on the difficulties of developing the application. The issue the expert mostly focused on was the fact that in education, immediate feedback is important for the users to know if they have done their work correctly. However, in games such as puzzle games too much immediate feedback may make the tasks too easy and solvable by trial and error instead of using math. Finding the middle ground between too much feedback and too little adds to the complexity of creating tasks. Other problems that were brought up are the difficulties of creating a good story without experience, and creating tasks that are easy to understand, but also difficult enough to be called puzzles.

The expert suggested that tasks might be created to support the use of the environment more. He suggested creating a puzzle to find a burrowed treasure under the surface of Mars by using measurements of length and angles. This would give a better connection between the story and geometry.

5.3.4 Math teachers at the NKUL 2019 conference

The application was displayed and tested during the NKUL 2019 conference. During the conference, three math teachers tested the application and answered a short questionnaire. The teachers were also asked to give a further explanation of why they gave their answers. Only one teacher gave written feedback in the questionnaire, while another gave feedback verbally after the test. The questions in the questionnaires were written in Norwegian. The questions have been translated when presented in this section. The original questionnaire can be seen in Appendix A.4.

The teachers were asked if they believed the application could be used to increase the understanding of geometry and to increase the motivation of first-year high school students. All three answered agree to both questions when given choices from strongly disagree to strongly agree, as seen in Figure 51.

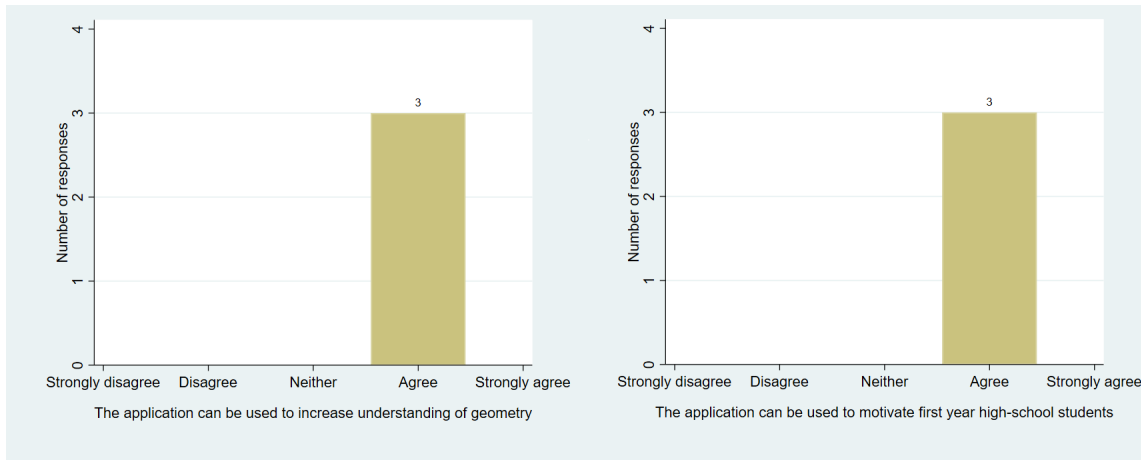


Figure 51: Math teachers level of agreement on if the application can be used to increase understanding of geometry (left) and if the application can be used to motivate first year high school students (right)

One teacher answered that the motivating factor of the application was why he believed it could increase understanding. It could motivate especially students with difficulties in maths and therefore give the wanted effect. When asked why they believed it would be motivating, they answered that it would be more fun and play rather than a typical school lesson. Also, the maths are made more concrete and practical, whereas struggling students typically have difficulties with abstract thinking in mathematics.

The other teacher that gave further answers mentioned that in their experience, the first year high school students that take vocational education typically struggle with maths. The teacher believed the application could be used for these classes because of motivational benefits and even stated that this was "finally something I can use." This teacher also mentioned that the more practical and visual way of presenting maths could give better motivation.

To summarize, the teachers believed that the application could increase understanding, but mostly as a secondary effect. They believed that the real value was in the engaging and motivating effect. The more concrete and practical way of doing math could help especially students with difficulties with both understanding and motivation.

6 Discussion & conclusion

This chapter will discuss the meaning of the results from the evaluation with regards to the theories presented in this thesis. It will also look at the limitations of the project. Further, the answers to the research questions are presented, in addition to a list of contributions. Lastly, it will make suggestions for future work.

6.1 Discussion

The findings from this study suggests that a VR-application with game elements has the potential to help some students to further their understanding of geometrical concepts in several ways. These findings, together with development problems and requirements, will be discussed below.

6.1.1 Motivation

The results suggest that the application has a positive effect on motivation. The students, in general, felt more motivated in the application than in a normal geometry lesson, with a statistically significant difference ($p=4.9\%$). This result fits with the feedback given by the expert in didactics, which thought the application had several elements that could be positive for motivation. One of these elements was the story in the application, to which 67% of the participants were positive. This might indicate that this is an element that has positive effects on student motivation. Dörner[14] supports this since the use of a story is one of the elements that can give motivation by evoking emotions. The environment and sounds can also influence motivation, as mentioned by the didactician. As seen from the results, most students had a positive attitude towards these. All this, seen together with the positive results for motivation, might suggest that the use of an environment and sounds has a positive effect on motivation. The didactician also mentioned that these elements would make the application seem like a game, and serious games have been shown to be a positive factor on motivation in most cases (See Section 2.2). Besides, the novelty of VR could, in itself, be motivating for many students. The teachers at the NKUL conference did also generally agree on

the idea that the application can increase the motivation of first-year high school students, which further supports the validity of the result.

6.1.2 Focus

The results gathered suggest that the application can have a positive effect on students' focus. A statistically significant difference ($p=0.55\%$) is seen between students self-efficacy of their ability to keep focused in the application as opposed to in a math lesson. This positive effect on focus is somewhat surprising when seen in relation to the feedback from the expert evaluations. Both these experts gave feedback on issues with the tasks that could produce some noise. From cognitive load theory, described in Section 2.4, one can see that this noise could negatively affect the attention and working memory of the users. One explanation to this could be that VR immerses the user and shelters the user from external disturbances. The application might subject the user to less outside noise than what can be found in a normal math lesson. Students might also have been motivated to keep their focus in the application. A motivated student might want to solve the tasks and therefore has an incentive to keep focused.

6.1.3 Understanding

The results show that most students thought that they got a better understanding of the different geometrical concepts in the application. This suggests that the application can have a positive impact on students learning outcome. We can not say this for certain since measuring learning outcome was outside the scope of this project. The expert of didactics thought there were some good parts in the application. The best part was the part of the first task where one modifies rectangles and rectangular prisms. These let the user explore with several solution paths, which follows phase 4 of Hiele's theory, described in Section 2.3.2. The expert was in general positive to using VR for learning geometry, and so was the teachers at the NKUL conference. The students of pedagogy at NTNU that gave feedback from phase 1 also thought that the application had potential, and then especially for students with difficulties.

By observing how the student solved the different tasks, we gained some insight as to how the students were thinking. Some of the students started to count cubes or rectangles to calculate the volume or area of a rectangular prism or plane. However, they only counted the outer layer of cubes and did not take the inner cubes into consideration. These observations match the findings described by Owens and Outhred[21]. As the students explored and tested their hypotheses, they eventually figured out that there also were cubes inside the rectangular prisms. This indicates that the students changed their concept image of the volume of a rectangular prism through the application.

Some students gave up on certain tasks and had to ask for the solution to these problems. This indicates that the need for different levels of difficulty is important. The task that most students

had problems with follows phase 4 of Hiele's theory, where the student solve and explore problems (see Section 2.3.2). It is hard to say at what phase the students were, but it would be natural for students at a lower phase to have problems with solving the task. It is therefore essential to design the task for certain phases and have a teacher say when the students are ready. We recommend building applications that focus on phase 1, 2, and 4 as these are the phases were the teacher do not have to direct the learner's intention.

6.1.4 Mathematical Anxiety

The results suggest that the application can be especially useful for students with difficulties in mathematics. The math teachers at NKUL 2019 believed that the application could be useful, especially as a way to motivate struggling students. The practical and concrete nature of the application might also help students that struggle with more theoretical and abstract math. This also fits with the work from Hao-Chiang[32] that found positive effects on spatial abilities in students with low or average academic achievement. Mathematical anxiety is also an issue some students struggle with [24]. 47% of the respondents to the pre and post questionnaires can have symptoms of mathematical anxiety in geometry math lessons. Fewer of the respondents experienced the same symptoms when testing the application. The difference is, however, not statistically significant. There was also very little difference between the results on to what degree students felt "stupid" in a math lesson as opposed to how they felt in the application. One could assume that students would feel better in the VR application because it removes the possibility for others to see them fail. The data did, however, not support that assumption. One reason could be that disturbances from the testing environment negated the effect of being in VR. Testing was done two to four participants at a time, and the participants were observed.

6.1.5 Requirements

The requirements made for the application seems, from the results, to be good. As discussed, the application based on these requirements has been suggested to improve motivation and show potential for use in learning geometry. Further, the expert of didactics in mathematics stated that they were good, general requirements for a VR application for geometry learning. This list, however, is not final, and additional requirements can be added. Two suggestions are:

- **The tasks in the application should support experimentation**

From the interview with the didactician, we found that experimentation is something many can learn from. This is also something that fits with the way teaching is done through constructivism, described in Section 2.4.

- **The application should avoid having too much sensory stimulation**

From cognitive load theory, described in Section 2.4, users' attention and working memory can be negatively affected by too much stimulus. From the expert interviews, we also see that

the current application might have this issue.

6.1.6 Problems

During the development of the application, many problems or challenges that should be taken into consideration when developing similar applications were encountered. During the development, evaluation, and research phases, a list of these problems was accumulated. These problems are:

1. Finding a good balance between game design and task design

One of the main challenges is to find a good balance between game design and task design. As the expert of serious games mentioned, the pyramid task where the user places pyramids on pillars does not give the correct feedback when it comes to learning-theory (see Section 2.3.3). This is a compromise between learning and playing, and it is not apparent how to compromise.

2. Finding a good balance between story, feedback, environment, and tasks

When bringing these elements together, one has to be careful not to add too much "noise" as mentioned by the expert in didactics of mathematics. This fits with theories of cognitive overload where the user loses focus due to too much information. When designing the application, one should find a balance between story, feedback, environment, and tasks as not to reach cognitive overload.

3. Giving constructive feedback

One of the problems encountered during development was giving constructive feedback in the application. Feedback should be intimate and individual, which is hard when creating a generic application for students in general. It was especially challenging to know when to give negative feedback, which is also important, see Section 2.3.3.

4. Creating a good story

Creating a good story has been, in our experience, a difficult task. A story should be engaging and fun while at the same time focusing users' attention on the tasks at hand. In our case, the story was created after the tasks. This resulted in the story not being as interesting and closely connected to the tasks.

5. Creating many good tasks

From experience gained throughout this project, we have found that creating good tasks is a complicated and time-consuming matter. Many different aspects need to be kept in mind when creating tasks. As stated in the requirements, tasks should: not have an instructional sequence, give feedback, come in a wide variety of difficulties, and use physical interaction. This complexity makes it challenging to create tasks that suit the level of several students, even within the same class.

6.1.7 Research questions

- **Main Question: How can a VR-application with game elements help students learn geometry?** A VR-application with game elements has the ability to increase users' motivation and focus. It also has the potential to be used to improve understanding of geometry. By use of VR, the student can explore and modify three-dimensional figures to create a better concept image for themselves.
- **RQ1: What are reasons for the use of VR in teaching geometry?**
VR is a great tool for spatial visualization and interaction[5], and can be used to improve spatial abilities. VR is also a tool that allows for first-person experiences that are impractical otherwise, e.g., manipulating the sizes of big shapes.
- **RQ2: What are the requirements for such an application?**
Twelve requirements have been made on the basis of research and testing, which can be found in Section 5.1. Two additional suggestions are found in Section 6.1.5.
- **RQ3: What are the problems with developing such an application?**
Many problems that should be taken into consideration were encountered throughout the project. A list of these is found in Section 6.1.6.
- **RQ4: How can the VR-application improve understanding of geometry?**
The results suggest that students may improve their understanding by experimenting with interactive figures and tasks with several solution paths.
- **RQ5: How can the VR-application help motivate students learning geometry?**
The VR-application can motivate students through an exciting environment, sounds, and certain game elements as puzzles and stories.

6.2 Limitations

This thesis has several limitations that might have affected the results. As this project is a master thesis, there was a limited time frame to create and evaluate the application. The number of participants in the final tests was also quite small. From talks with a didactician, we found that testing for learning outcome was something that would be outside the scope of this thesis.

The results gathered from testing on high school students might be positively biased towards VR and games in general. Most students believed VR could be used for learning geometry prior to the test. This test also gave the participants a break from a regular mathematical lesson, which might also have affected the results.

The environment of the test was also not ideal. Two to four participants tested the application

simultaneously in the same room. This may have affected the students' experience of the application due to external disturbances. There were also some technical issues during the tests where the Oculus Rift was used. A few students experienced some tracking issues that interfered with their experience of the application and potentially resulted in a loss of immersion.

Another limitation is that the difficulty of the tasks seemed not to suit the level of all the participants. This might have affected the results. However, due to our inexperience and the complexity of creating tasks, it was not realistic to create several levels of difficulty in the time-frame of the project.

It is important to note that we are students of informatics, not pedagogy, and have no prior experiences with the pedagogical theories that are used. Therefore there might have been misunderstandings or misinterpretations of some theories that are used throughout this thesis.

6.3 Contribution

This master thesis has resulted in several contributions. The first and most obvious contribution is the VR application for learning geometry that was developed during this project. For this application, we created and evaluated a list of general requirements that can be used when creating similar applications. Two suggestions for additional requirements were also presented. A list of the main problems and challenges with developing such an application was accumulated. Furthermore, by evaluating the application, we gained insight into the potential benefits of using VR for learning geometry. Lastly, insight into how the application contributed to the improvement of understanding and motivation in students was gained. The contributions are summarized in the list below.

- A VR application with game elements for learning geometry (Described in Section 5.2)
- A set of general requirements for the development of a such an application (Presented in Section 5.1 and 6.1.5)
- A list of problems that should be taken into account when developing such an application (Presented in Section 6.1.6)
- Insight into the potential benefits of using VR for learning geometry (See Section 6.1)
- Insight into how the application can contribute to improving understanding and motivation in students (See Section 6.1)

6.4 Future work

There are several ways the application developed during this project can be improved and researched further. The application can be used as a basis for many additional features. It would be interesting to add tasks and learning material for different geometrical concepts like previously

mentioned by the didactician of mathematics in Section 5.3.2. There are also some issues with the current application that could be fixed. Two requirements that address these issues have been added as suggestions in Section 6.1.5. These requirements are proposing to make the tasks, in general, more experimentative and reducing noise. The task regarding the volume of pyramids, described in Section 5.2.3, had some issues with making students understand its learning outcome. This task will need some reworking, and the expert in didactics of mathematics suggests using animations to show the splitting and merging of the pyramids. The formula of a pyramid should also be presented to the user more directly. The task described in Section 5.2.2, had some issues with not being intuitive and should be reworked. One of the most promising elements of the application was the interactive figures of volume and area. These types of interactions should be explored further to maximize their learning output.

There is generally little research on the use of VR in teaching geometry. This study did not measure the effect of the application on students learning outcome. Measuring this effect would be prioritized if this study was to be continued. Researching the effects of the specific elements of the application, such as the story, environment, and puzzles could also be beneficial. A list of general requirements and two suggestions for further requirements have been presented in this thesis. Further researching the validity of these requirements could result in recommendations for how to develop VR applications for learning geometry.

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Appendix

A Documents

Taking part in the research project ” Immersive Technologies for Learning and Training ”

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

Purpose of the project

To conduct this research, we will need to analyze the use immersive technologies for learning and training in various contexts, including learning of language and mathematics, visualization of climate change, immersive exploration of historical manuscripts, workplace training and visualization of medical procedures. The goal is to develop innovative learning methods and tools using immersive technologies.

Who is responsible for the research project?

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

Why are you being asked to participate?

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

What does participation involve for you?

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

Participation is voluntary

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

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

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

What will happen to your personal data at the end of the research project?

The project is scheduled to end 31.12.2019. All data will be anonymized at the end of the project, e.g. audio and video will be deleted when transcripts and analysis of data are completed, except for selected video and photo material to be used for research purpose. These and anonymized recordings from the inside of the virtual environments may be used for demonstrations in research context in such a way that no information will be linked to individuals. Scientific reports and presentations from this study might contain recordings from the VR/MR/AR sessions, questionnaire results, anonymized photos/videos from the sessions and anonymized citations from the interviews.

Your rights

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

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

What gives us the right to process your personal data?

We will process your personal data based on your consent.

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

Where can I find out more?

If you have questions about the project, or want to exercise your rights, contact:

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

Consent form

I have received and understood information about the project **Immersive Technologies for Learning and Training** and have been given the opportunity to ask questions. I hereby declare my consent that my data in relation to Immersive Technologies for Learning and Training may be stored, documented and used for research and educational purposes as described above. I give consent for my personal data to be processed until the end date of the project, approx. 31.12.2019

(Signed by participant, date)

Spørreskjema

Dette spørreskjemaet er en del av en masteroppgave ved NTNU. Målet med dette spørreskjemaet er å samle inn data om bruken av Virtual Reality (VR) til læring av Matematikk. All data som blir samlet her vil bli analysert og brukt til å støtte forskningen vi har gjennomført. All data vil være anonym og kan ikke brukes til å identifisere deg.

1. Kjønn?

Markér bare én oval.

- Kvinne
 Mann
 Annet

2. Hva synes du om matematikk som et fag på skolen?

Markér bare én oval.

	1	2	3	4	5	
Misliker	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Liker godt

3. Hva synes du om undervisningen i matematikk på skolen?

Markér bare én oval.

	1	2	3	4	5	
Misliker	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Liker godt

4. Har du en kommentar til hvorfor det er bra eventuelt dårlig?

5. Kunne du tenkt deg å bruke VR i matteundervisningen?

Markér bare én oval.

- Ja
 Nei

6. Jeg fikk en bedre forståelse av volum/geometri etter å ha prøvd applikasjonen.

Markér bare én oval.

	1	2	3	4	5	
Ikke Enig	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Veldig Enig

7. Jeg følte meg engasjert mens jeg brukte applikasjonen.

Markér bare én oval.

	1	2	3	4	5	
Ikke Enig	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Veldig Enig

8. Hva synes du om applikasjonen?

Markér bare én oval.

	1	2	3	4	5	
Misliker	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Liker godt

9. Hva likte du best med applikasjonen?

10. Hva likte du minst med applikasjonen?

11. Var det noen oppgaver du hadde problemer med? Hvis ja, hvilke?

12. Har du noen andre tilbakemeldinger?

Mattel ring i Virtual Reality

Dette sp rreskjemaet er en del av en masteroppgave ved NTNU. Målet med dette sp rreskjemaet er   samle inn data om bruken av Virtual Reality (VR) til l ring av Matematikk. All data som blir samlet her vil bli analysert og brukt til   st tte forskningen vi har gjennomf rt. All data vil v re anonym og kan ikke brukes til   identifisere deg.

Mattel ring i VR f r test

Denne delen skal du svare p  f r du pr ver VR-applikasjonen

1. Hvor gammel er du?

2. Hvilket kj nn har du?

Mark only one oval.

- Mann
 Kvinne
 Annet

3. Har du pr vd VR f r?

Mark only one oval.

- Ja
 Nei

4. Velg det alternativet du f ler passer best for deg

Mark only one oval per row.

	Sterkt uenig	Litt uenig	Verken enig eller uenig	Litt enig	Sterkt enig
Jeg interesserer meg for dataspill	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Jeg tror VR kan v�re bra for l�ring	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Jeg tror VR kan bli brukt til � l�re geometri	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

5. Hvorfor tror du / tror du ikke at VR kan bli brukt til   l re geometri?

6. Velg det alternativet du f ler passer best for deg*Mark only one oval per row.*

	Sterkt uenig	Litt uenig	Verken enig eller uenig	Litt enig	Sterkt enig
Jeg f�ler meg motivert i en vanlig mattetime	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Jeg f�ler meg "dum" hvis jeg har problemer n�r jeg jobber med matematikk	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Jeg kan f�le anspenhet eller engstelighet i mattetimer om geometri	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

7. Velg det alternativet du f ler passer best for deg

Jeg er sikker p  at jeg kan...

Mark only one oval per row.

	Sterkt uenig	Litt uenig	Verken enig eller uenig	Litt enig	Sterkt enig
L�re det grunnleggende i ny teknologi	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
L�se de fleste volum/areal oppgaver fra pensum	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Holde fokus i en mattetime om geometri	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
F� bedre forst�else av geometri i en vanlig mattetime	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Mattel ring i VR etter test

Denne delen skal du svare p  etter du har pr vd VR-applikasjonen

8. Hva synes du var de tre BESTE tingene ved applikasjonen? (Vennligst pr v   nevne tre ting)

9. Hva synes du var de tre VERSTE tingene ved applikasjonen? (Vennligst pr v   nevne tre ting)

10. Hvordan ble l ringsopplevelsen din p virket av   v re i et virtuelt milj ?

11. Ville du foretrukket   utf re oppgavene uten historien og med mer n ytrale omgivelser?

Mark only one oval.

- Ja
- Nei

12. Hvorfor eller hvorfor ikke?

13. Velg det alternativet du f ler passer best for deg

Mark only one oval per row.

	Sterkt uenig	Litt uenig	Verken enig eller uenig	Litt enig	Sterkt enig
Jeg f�lte meg motivert til � gjennomf�re oppgavene i applikasjonen	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Lydene i spillet gjorde det engasjerende � utf�re oppgavene	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Jeg f�lte det var interessante omgivelser	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Det var lett � forst� at jeg hadde f�tt til en oppgave	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Det var lett � forst� hva jeg skulle gj�re	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Der var ikke vanskelig � forst� hvor jeg skulle g� for � finne oppgavene	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Jeg f�lte meg "dum" hvis jeg hadde problemer med � l�se en oppgave i VR applikasjonen	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Jeg f�lte anspenthet eller engstelighet i applikasjonen	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Jeg f�lte oppgavene i applikasjonen var for vanskelige	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

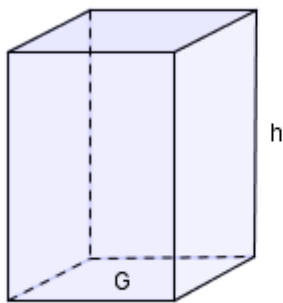
14. Velg det alternativet du f ler passer best for deg

Jeg er sikker p  at jeg kan...
 Mark only one oval per row.

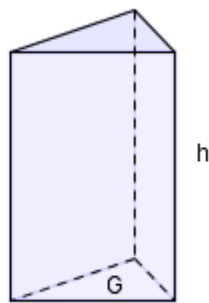
	Sterkt uenig	Litt uenig	Verken enig eller uenig	Litt enig	Sterkt enig
Holde fokus p� oppgavene i VR applikasjonen	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
F� bedre forst�else av geometri ved bruk av VR	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Bruke applikasjonen intuitivt uten hjelp	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
L�se de fleste volum/areal oppgaver fra pensum	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

15. Velg det alternativet du f ler passer best for deg

Ved   bruke applikasjonen fikk jeg bedre forst else av...



Rett firkantet prisme



Rett trekantet prisme

Mark only one oval per row.

	Sterkt uenig	Litt uenig	Verken enig eller uenig	Litt enig	Sterkt enig
Arealet av rektangler	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Volumet av firkantede prismer	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>
Volumet av pyramider	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

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NKUL spørreskjema

Dette spørreskjemaet er en del av en masteroppgave ved NTNU. Målet med dette spørreskjemaet er å samle inn data om bruken av Virtual Reality (VR) til læring av Matematikk. Dataene som blir samlet her vil bli analysert og brukt til å støtte forskningen vi har gjennomført. All data vil være anonym og kan ikke brukes til å identifisere deg.

1. Er du lærer?

Mark only one oval.

- Ja
 Nei

2. Hva er ditt fagfelt?

3. Tror du læringsapplikasjonen kan brukes til å bidra til bedre forståelse av geometri hos VG1 elever?

Mark only one oval.

	1	2	3	4	5	
Sterkt uenig	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Sterkt enig

4. Hvorfor, hvorfor ikke?

5. Tror du læringsapplikasjonen kan brukes for å motivere VG1 elever?

Mark only one oval.

	1	2	3	4	5	
Sterk uenig	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	Sterk enig

6. Hvorfor, hvorfor ikke?

7. Hva ville du gjort for å forbedre applikasjonen?

8. Har du noen flere kommentarer?



