# VR from a Learning Perspective

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**Abstract**

There are many examples of using technology in schools for enhancing student's learning experience. A relatively unexplored technology in education is Virtual Reality. Most of the existing VR applications aimed at learning are passive virtual field trips, where the user only interacts with the application by observing the virtual world. This thesis explores if interactive Virtual Reality applications can have a positive effect on high school students' learning and engagement when it comes to learning the basics of natural science. This was done by developing a Virtual Reality application and testing it on high school students. The thesis also studies how a Virtual Reality application should be developed to function as a learning tool.

The application teaches the basics of electric circuits and was designed using a user-centered design process and by utilizing variation theory. Electric circuits was chosen as a subject, based on questionnaires and an interview with teachers.

A comparative study was performed with two groups of students; one group had a traditional lecture and the other used the Virtual Reality application. Both groups were then tested on what they had learned and the second group answered a questionnaire about their experience with the application.

The results of the test show that the students enjoyed using Virtual Reality as a learning tool and that they were able to learn. Due to the small sample size and the short time each student had with the application, there was no conclusive answer to whether or not the students could learn better from a Virtual Reality application. However, it was concluded that Virtual Reality has great potential as a learning tool due to the immersive and interactive nature of Virtual Reality technology.

**Keywords:** Virtual Reality, Pedagogy, User-centered design, Variation theory, Interaction design.

**Sammanfattning**

Det finns många exempel på att använda teknologi i skolan för att förbättra elevers lärande. En relativt oanvänd teknologi i utbildning är Virtual Reality. De flesta VR applikationer som används i utbildning idag är passiva virtuella studiebesök, där användaren interagerar med applikationen genom att observera den virtuella världen. Detta examensarbete undersöker om interaktiva Virtual Reality applikationer kan ha en positiv effekt på elevers lärande och engagemang, när det kommer till att lära sig grunderna i naturvetenskap. Detta utfördes genom att utveckla en applikation och testa den på högstadieelever. Detta exjobb studerar också hur en Virtual Reality applikation bör utvecklas för att fungera som ett lärandeverktyg.

Applikationen lär ut grunderna i elektriska kretsar och designades med en användarcentrerad designprocess och baseras på variationsteori. Ämnet elektriska kretsar valdes baserat på enkäter och en intervju med lärare.

En komparativ studie utfördes med två grupper av elever; en grupp som hade en traditionell lektion, och en grupp som använde Virtual Reality applikationen. Båda grupperna testades på vad de hade lärt sig och den andra gruppen svarade på en enkät om deras upplevelse med applikationen.

Resultatet från testet visar att eleverna uppskattade användandet av Virtual Reality som lärandeverktyg och att de hade lärt sig av att använda applikationen. På grund av det låga antalet medverkande och att eleverna hade mycket kort tid med applikationen kunde inga konkreta svar ges på huruvida elever lär sig bättre med Virtual Reality. Dock visades det att Virtual Reality har god potential som ett lärandeverktyg på grund av Virtual Realitys uppslukande och interaktiva karaktär.

**Nyckelord:** Virtual Reality, Pedagogik, Användarcentrerad design, Variationsteori, Interaktionsdesign.

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# Abbreviations

**VR** ..... Virtual Reality

**UCD** ..... User-centered design

**Lo-fi** ..... Low fidelity

**Hi-fi** ..... High fidelity

**UI** ..... User interface

**SDK** ..... Software Development Kit

# CHAPTER 1

# Introduction

Technology appears everywhere today and is involved in almost every part of our lives. Among many things, it makes it possible for us to communicate, socialize and share information with each other in a nearly limitless way. With this great presence of technology, a particularly important question that this raises is how it affects us when it comes to learning. In schools today, it is not unusual that teachers take advantage of modern technology when educating students. By introducing technology in the classroom it can be used as a tool to aid students in the process of developing greater understanding e.g. visualization of abstract subjects that are hard to relate to. Examples of common technologies that are already used in education are smart boards, personal computers and lately tablets and phones with various applications, which are all used as an aid to take education to a new level.

A relatively new and unexplored technology that has more recently emerged is Virtual Reality. VR is a technology platform that uses a computer to simulate a three-dimensional image of an environment where it is possible for a person to, in a physical way, interact with its content by using equipment like a headset and controllers [1]. This new technology is becoming more popular in the gaming industry where games are created that engages the player physically in order to make the experience as real as possible.

Virtual Reality is not only created for experiencing games in a 3D environment. In fact, VR has great potential as a learning tool in education. With VR it is possible to create simulated environments where students are able to interact with its virtual objects and affect them using controllers. In a teaching environment, the goal with this tool is at first to increase students' ability to learn by creating an experience where it is possible to move around, interact with and understand the action of doing so, in the virtual world. Designing a learning experience could, of course, be done in the real world as well, but sometimes there are physical limitations that make the virtual world a better choice. Secondly, VR can also be seen as an attempt to increase the motivation among students, which is an important aspect of learning.

There are already a few examples of Virtual Reality in the classroom where

students can dive and explore Titanic, visit the International Space Station, or watch a live surgery [2, 3]. The problem with these experiences is that they do not relate to an average high school, where the students have to learn the basics of chemistry, math, biology, and physics.

## 1.1 Jayway

This master thesis was done on behalf of the IT consultant company *Jayway* who wanted to investigate and do more research in the field of Virtual Reality when it comes to education. The thesis was from the beginning a suggestion from the company itself that later developed into a suitable project for both parts. During the project, Jayway provided all the tools necessary to complete this master thesis and have always been there to help out if needed with their more extensive knowledge in the field of VR.

## 1.2 Purpose

The main purpose of this master thesis was to research: *if the use of Virtual Reality in education could have a positive effect on high school students' understanding and engagement when it comes to learning the basics in the field of natural science.* In addition to this main question, the following questions were asked in the beginning of the project:

- How does this learning technique differ from traditional learning where books and lectures are the primary sources of fact and information?
- Are there any differences in students' learning curve, increase of learning over time?
- How does this technology affect students' engagement when it comes to taking on and resolving new assignments?
- How can a virtual environment be created that is pedagogically correct and helpful as a learning tool when learning about the natural sciences?

With answers from the research of this master thesis, the intention was from the beginning to raise the question if Virtual Reality has the potential of being introduced in education, by answering the questions above. Another aim of the project was to identify some important aspects that need to be fulfilled in order to make Virtual Reality viable in education.

## 1.3 Scope

In the beginning of the process, a scope was defined that in more detail clarified the boundaries of the project and what phases were needed in order to meet the

requirements of this master thesis. The details of the scope can be seen below.

This master thesis in collaboration with *Jayway* investigates how Virtual Reality performs compare to the methods used today when it comes to learning new objects in a specific field of natural science. How could VR be a suitable tool in future education that enhances the experience and thereby the ability for students to learn?

In order to answer these questions the following tasks needed to be completed in this project:

- Conduct a study with teachers to investigate which areas in natural science education that could benefit from introducing visual and interactive tools that might aid students in their understanding.
- To be able to create a virtual environment for learning, a big part of this thesis will be to study pedagogy. Without this knowledge, the intention of creating something that can be used by students in the future to make learning easier will not be possible.
- To actually be able to create the virtual environment the programs used for designing and implementing it needs to be learned.
- Develop a VR application using a *user-centered design process* to get an experience and suitable tool that the end-users appreciate and want to use.
- Perform a user-test on high school students in order to measure how the learning effect differs using the created VR application compared to how they learn today.

The VR application would be developed with the purpose of working for Oculus Rift. This decision was made due to the company already is in possession of this VR equipment.

The duration of this master thesis was 20 weeks that once completed would deliver a fully functional VR application. The goal of this application was to cover one area of difficulty, e.g. an abstract or hard grasping subject, where the area was based on the conducted study and answers from teachers.

# CHAPTER 2

# Theoretical Background

In order to create a Virtual Reality application with a good user experience, a couple of aspects need to be considered. Firstly, the design of the VR application needs to involve and be centered around the end-user from the beginning. Secondly, no matter how good the 3D modeling of the virtual environment is, the pedagogical part of learning something new by interacting with its content must be involved in the process. Without an understanding in the basics of how people learn, this application will never develop into a viable learning tool in future education.

In this chapter the theoretical parts of designing an application that will contain these properties will be clarified.

## 2.1 User-centered design

User-centered design (UCD) is an iterative design process which focuses on the end-user's needs and requirements [4]. UCD consists of four different activities: *observation*, *idea generation*, *prototyping* and *testing*, shown in figure 2.1 [5]. The goal with this process is to achieve a high degree of usability and the best possible user experience by focusing on the user and the intended *use situation*. The three main principles of UCD recommended by Gould et. al. [6] are:

- *Early Focus on Users and Tasks*. The designer must understand the user and in what context the product is going to be used.
- *Empirical Measurement*. Prototypes should be developed and tested by the end-user, and the results from these tests are observed and recorded.
- *Iterative Design*. The design should be tested, evaluated and redesigned iteratively.

Involving the user when specifying the requirements ensures that the right product is produced. In the beginning of a project this is usually accomplished using questionnaires or interviews. The information gathered from the questionnaires

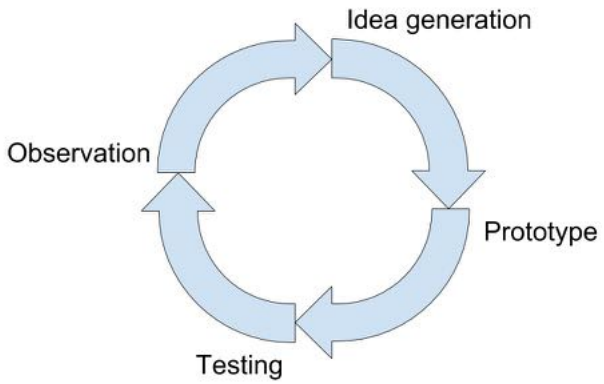


Figure 2.1: Iterations of the design process as described by Norman [5].

and interviews are used to generate ideas and specify requirements. Based on these ideas, prototypes are developed and tested. UCD is described by Arvola [7] as having three distinct phases.

- *Conceptual design phase.* This phase consists of data collection, observations, and analysis. Goals and intentions are specified.
- *Processing phase.* The functions and contents of the product are developed based on the results of the conceptual model created in the previous phase.
- *Detailing phase.* Detailed specification and prototypes are created.

### 2.1.1 Questionnaires

One of the advantages of using questionnaires to gather data is that they can more easily be distributed to a larger amount of participants [8]. Using questionnaires early in a development process facilitates an early focus on users and tasks.

A disadvantage of questionnaires is that, unlike direct interviews, the author of the questions is not available to clarify or explain the questions. Therefore the questions should be as specific as possible [8].

### 2.1.2 Interviews

Interviews are a way to follow-up answers from e.g. a questionnaire. This face-to-face method is more direct, offers the possibility to ask follow-up questions, and is more flexible. Before an interview is conducted, it is important to prepare and structure the interview to get the most from it. The questions in an

interview could either be open or closed. An open question could, for example, be: "What did you expect to happen when you...". A closed question would rather be: "Did it happen as you expected?". Open questions are suitable when the goal of the interview is exploratory and closed questions should only be used when the possible answer is known beforehand. Typically, an interview that only has open questions is called unstructured and one that only consists of closed is structured. A mix of the questions would, on the other hand, be called semi-structured [8].

### 2.1.3 Scenarios

Designing scenarios is a tool for communicating ideas about user actions. This is done by creating a model of a situation or an activity that the user is experiencing or will experience. This model can then be used to express suggestions of a user situation or design concept as an extension of the *conceptual design*. By reading the scenario the ideas and key interactions behind a product could more easily be understood and shared among team members, design team, and potential customers. The scenario is written as an informal story [8].

### 2.1.4 Prototyping

Working with prototypes enables the designer to involve the user earlier in the design process. There are two major methods of prototyping: *Lo-fi* and *Hi-fi*. *Lo-fi* prototypes have limited functionality and are most often used to communicate design alternatives and to demonstrate ideas [9]. Two advantages of *Lo-fi* prototypes is their low cost and rapid development. However, they have limited use later in development. *Hi-fi* prototypes are generally much more detailed and commonly used for user-tests since all or most of the functionality is implemented. However, this means that they are more expensive to produce [9].

## 2.2 Pedagogy

The field of pedagogy studies the theory, activities, and methods of teaching. Marton and Booth describes three aspects of learning, the *agent* of learning, the *act* of learning, and the *object* of learning [10]. The *agent* of learning describes what initiates the learning. The *act* of learning describes the intentions of the learning experience, e.g. memorizing or understanding something. The *object* of learning describes the content, meaning or phenomenon which is learned. The *object* of learning can be divided into *direct* and *indirect object* of learning. The *direct object* of learning is the content of what is being learned and the *indirect object* of learning describes what the *act* of learning aims at, i.e. the capabilities the learner is expected to develop. In other words, the *indirect object* and the *act* of learning describe the *how* aspect of learning and the *direct object* of

learning describes the *what* aspect (figure 2.2).

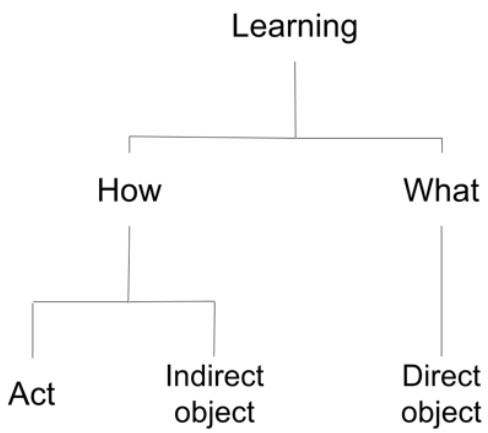


Figure 2.2: The basic structure of learning as described by Marton and Booth [10].

Marton and Booth also describe three temporal facets, or phases, of the learning experience. These three facets are: *acquisition*, *knowing*, and *making use of* [10]. The *object* of learning can be seen as the link between the three temporal facets.

### 2.2.1 Variation theory

Marton and Booth propose designing learning experiences around variation [10]. They argue that in order to differentiate between aspects of a phenomenon it is necessary that something varies [10]. From a variation theory perspective, learning is being able to discern differences [11], e.g. something changing from one state to another. Variation theory has a strong focus on the *object* of learning [11]. An example of this is given by Marton and Pang [12], who conducted a learning study about necessary conditions of learning. In this study the *direct object* of learning was "*the effect of a simultaneous change in demand and supply on price*". The capabilities that the students were expected to develop, i.e. the *indirect object* of learning, was to be able to determine a new price based on the supply and demand. By independently varying the supply and demand the students can discern the effects on the price. In this case, one dimension of variation varies and the other remains invariant. In variation theory, this is known as *separation* [12], which according to Marton and Pang is one of four necessary conditions for learning. The other three are: *contrast*, *generalization* and *fusion*. *Contrast* means that something cannot be discerned unless the learner simultaneously experiences a mutually exclusive aspect of the same phenomenon [12].

## 2.3 VR in Education

Because of the interactive, immersive and multisensory nature of VR, there are many examples of Virtual Reality training and learning applications. Two companies working on VR learning applications are *Immersive VR Education* [2] and *Unimersiv* [3]. Most of the VR experiences from these companies are virtual field trips, allowing students to travel to historic or inaccessible places, e.g. Titanic or the International Space Station. Google has created a similar application called Google Expeditions [13], which contains over 200 virtual field trips. This application allows the teacher to guide the students by selecting parts of the scene and directing the student's attention to that specific part. The teaching material is also supplied by the application (figure 2.3). These applications are often passive experiences, with little interaction from the students.

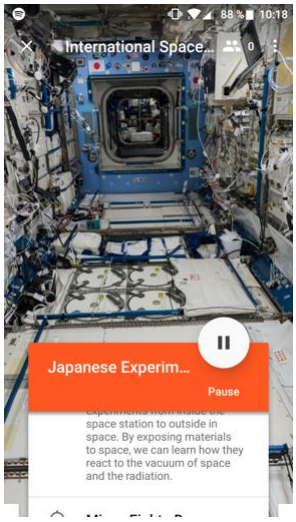


Figure 2.3: A field trip to the International Space Station in Google expeditions

In addition to these educational applications there are also many examples of Virtual Reality training applications, such as crane and rigging simulators [14] and surgery training simulators [15]. These type of application are often more interactive and allows the users to practice their skills. The major advantage of these applications is that situations which are either dangerous or extremely sensitive can be practiced without risk.

# CHAPTER 3

# Technical background

This chapter briefly explains what Virtual Reality is and what equipment that is required in order for the user to experience and interact with the virtual environment. It also covers which tools were used in this project for developing the VR application.

## 3.1 Virtual Reality

Virtual Reality is a technology that uses computer software to generate a three-dimensional realistic image of an environment where the user's physical movement is simulated. By using equipment, e.g. a headset with a screen and controllers that have sensors to track the user's movement, it is possible to interact with the virtual environment [1]. Examples of interactions which the user is be able to perform, depending on the implementation of the virtual environment, is to lift, move and affect virtual objects.

### 3.1.1 Oculus rift

Oculus Rift is a Virtual Reality headset, developed by the company Oculus VR, that make it possible for a user to experience a virtual environment e.g. playing VR games, watching VR movies or just be part of a VR environment [16].

Figure 3.1 shows the Oculus Rift headset, which has adjustable straps to ensure a good fit. The headset also comes with built-in headphones that make it possible for the user to experience audio in the virtual environment. At the front, there is a screen which runs on 2160x1200 at 90Hz split over two displays, one for each eye [17].

Figure 3.1: Oculus Rift headset

Figure 3.2 shows the two controllers needed in order for the user to interact with virtual objects in the virtual environment. The list below shows the button layout for the controllers.

1. Button X
2. Button Y
3. Trigger Button
4. Thumb Stick
5. Button B
6. Button A
7. Hand Trigger

In figure 3.3 one of the two sensors that come with Oculus Rift is shown. These are used for tracking the headset and the controllers the user are holding.


Figure 3.2: Oculus Rift controllers

Figure 3.3: Oculus Rift sensor

## 3.2 Unity

Unity is a game engine developed by Unity Technologies [18]. Unity supports development for both 2D and 3D games for multiple platforms, e.g. mobile, consoles, and Virtual Reality.

The main editor (figure 3.4) consists of panels which can be customized by the user. In the center of the editor in figure 3.4 is a view of the current *scene*. Objects in the *scene* are called *game objects*. Components, e.g. colliders and animations, are added to *game objects* via the inspector. Scripting can be done in multiple programming languages such as C#, Javascript and Boo.

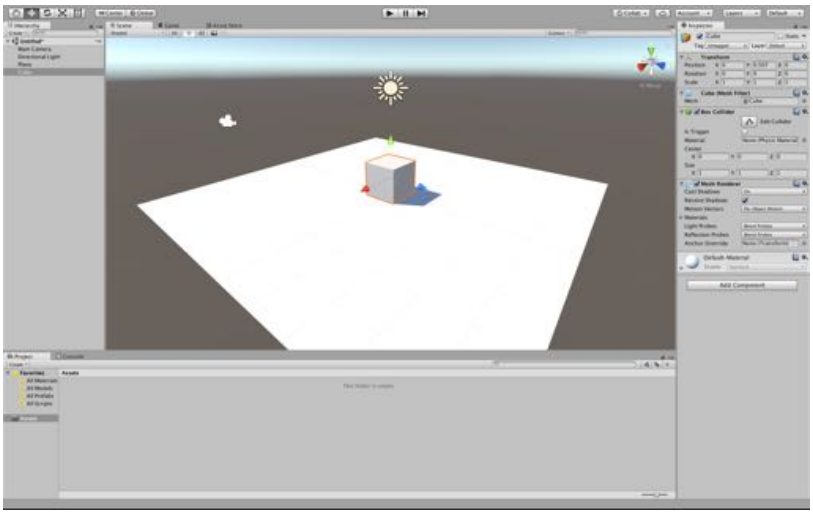

Figure 3.4: Unity game engine editor

### 3.2.1 SteamVR and VRTK

SteamVR is a plug-in developed for Unity and is available as a free download in Unity Asset Store [19]. SteamVR supports all major Virtual Reality headsets, including render models for controllers. When the VR application is running, Unity's game window shows the same video feed as the one sent to the headset.

VRTK is an open-source scripting library which expands the VR capabilities of Unity and SteamVR [20]. It contains scripts for many of the basic VR interactions, such as grabbing and using objects, teleportation, and pointers. VRTK makes it easy to develop for different VR headsets and controllers by simply selecting the right SDK.

## 3.3 Blender

Blender is a free and open source 3D modeling suite [21]. It can be used to create more advanced *game objects* and *assets* for Unity. The creation of a new game object in Blender typically starts with a primitive *mesh model* shape e.g. plane, cube, and sphere. A mesh is a representation of a 3D-object that has a collection of vertices, edges, and faces. A vertex represent a single point, an edge is a line segment that connects two vertices and a face is a surface that is enclosed by edges [22]. Figure 3.5 is captured from Blender itself where the different parts of a primitive cube are selected one by one.

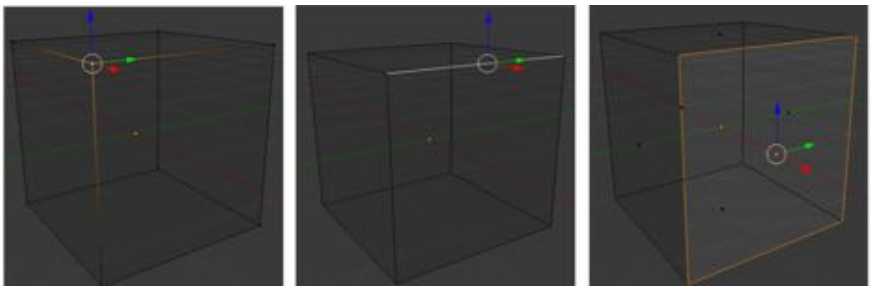

Figure 3.5: Captured image of vertex, edge and face selected in Blender

# CHAPTER 4

# Method

This chapter presents the methods used to develop the Virtual Reality learning application. The process was divided into four phases according to figure 4.1. Firstly, a literature study was conducted to gather knowledge about pedagogy and user-centered design. Following this phase was the conceptual phase, which included two questionnaires and an interview to collect the data needed for this project. Thirdly, the application was developed in iterations of two weeks. Lastly, a user-test was conducted with high school students.

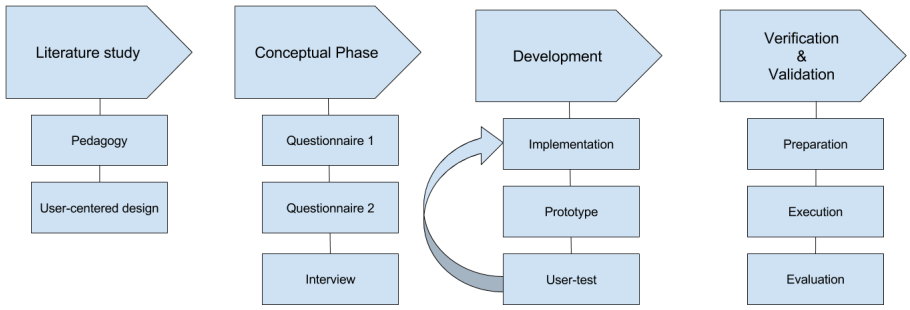


Figure 4.1: The project process

## 4.1 Conceptual Phase

In the beginning of this master thesis the question "*How could Virtual Reality be used from a learning perspective?*" raised many ideas and thoughts of areas to visualize in VR. With a degree in engineering, where some subjects often tend to be abstract and hard to grasp, e.g. linear algebra, physics, and chemistry, visualization could be very useful. Think about the possibility of drawing

vectors, planes and other shapes in a virtual environment where you can experience it all in 3D. Another example could be studying what happens if two molecules collide, how they react, and actually be able to see a graphical 3D representation of it.

Despite all ideas and thoughts in the beginning of this project, the target group of the VR application was high school students who study the basics of natural sciences. By following the first principle of user-centered design, *early focus on users and tasks*, it was necessary to understand what specifically is difficult for students to learn and to find out the correct context. In order to get this type of information, it was therefore determined that the best answers are probably given by their teachers. That led to the first step of this project, which was to create a questionnaire for teachers. The goal of the questionnaire was to gather their expertise and experience of difficulties that they have encountered when teaching. Their answers would be used as a basis for determining what subject to choose to develop the application for.

### 4.1.1 Questionnaire 1

With experience from earlier projects, it was determined that this first questionnaire was going to be an exploratory pilot test. The reason for this was to make sure that the questions were understandable and that the data gathered was useful. Due to this, only two teachers at one school received the questionnaire. In appendix A all the questions asked in questionnaire 1 are listed and the corresponding result can be seen in chapter 6.

### 4.1.2 Questionnaire 2

With answers from questionnaire 1, it was decided to change question three and four since they needed to be more specific in order to get more concrete examples from the teachers. These two questions were seen as the key questions in the first questionnaire. Therefore this change was necessary to be able to choose which subject to implement in the VR application. In comparison with question two and three from the first questionnaire listed in appendix A the modified version of them can be seen below with the changes in italic.

3. Which parts in your field of education do you have experience of students having difficulty, or is more difficult than other parts, to understand/remember? Please describe this part *and give concrete examples e.g. optics, chemical reactions, photosynthesis.*

4. Why do you think students experience this part to be more difficult and hard to grasp when it comes to learning it? *Please give concrete examples.*

With these two questions clarified, questionnaire 2 was sent out to a larger number of high school teachers. The questionnaire was sent out through the teachers' union to all high school teacher that teach natural science in the region. The questionnaire was answered by seven teachers.

### 4.1.3 Electric circuits

Based on the result from questionnaire 2 it was decided that electricity was a suitable subject to visualize in VR. This decision was made due to specific answers from the teachers where some of them pointed out electricity as an area where students have difficulties. The problem is that abstract things which happen on a molecular level and that are not visible to the human eye, is much harder to visualize and relate to. One teacher also pointed out that they were missing descent lab equipment at the corresponding school.

Apart from the answers from the teachers, this subject seemed from the beginning to be on an appropriate level to develop in VR, due to lack of previous knowledge of working with this platform. It is not easy to develop this type of application without knowing the limitations of the platform.

Another reason for choosing electricity was that from the obtained basic knowledge in pedagogy and variation theory, this subject made it easy to relate to and transfer the information learned about variation into the developed VR application.

When it comes to electricity the basics lays on the relationship between voltage, current, and resistance. The formula that describes this relation is Ohm's law, $U = RI$. This formula expresses the ratio of potential difference in volts where $I$ is the current in amperes and $R$ is the resistance in ohms. Another formula that can be used to calculate the electric power is $P = UI$ where $P$ is in watt.

In order make use of variation theory it was decided that *electric circuits*, that includes components that are able to vary these aspects, was the best way to design the learning experience. This design will be explained more in section 4.1.6.

### 4.1.4 Interview

As a follow-up to the questionnaire, an interview was performed with a teacher at Lerbäckskolan in Lund. The interview lasted approximately 45 minutes and was divided into two parts, one for further exploring what students find difficult in the the field of electronics, and the second for discussing alternative ways of conducting the final user study. The interview was prepared as an *open* (*unstructured*) interview [8]. A transcribed and translated version of the first part is shown in appendix B and compiled results are shown in 6.3.

### 4.1.5 Scenario

A scenario was written to define the key interactions and ideas with the application from a user's perspective. The scenario is presented below.

> A student stands at a table in a classroom. In front of her is an assignment to construct an electrical circuit using a battery, resistor, and light bulb. The assignment also specifies that to complete the assignment she has to set the values of the components, such that

> the resulting current is 4 ampere. With her left hand, she opens a toolbox containing the components she has been instructed to use. She grabs the components and places them on marked locations on the table and connects them using clips and wires. When the circuit is closed the light bulb lights up and she can see the direction of the current and electrons in the wires. She then sets the voltage to 8 and the resistance to 2 and completes the assignment.

### 4.1.6 Designing the learning experience

The first step in designing the learning experience was to define the *object* of learning. One of the learning goals in the syllabus for high school students states that a student should comprehend:

> "The relationship between voltage, current, resistance and effect in electrical circuits and how they are used in an everyday context."[23]

This learning goal was also cited by the teacher in the interview. However, the teacher mentioned other aspects of electrical circuits which he considered equally important. Initially the three objects of learning were defined as:

A The relationship between voltage, current, resistance, and power.

B The difference between series and parallel connections.

C The direction of the current and electrons in a circuit.

Since this thesis aims to evaluate VR as a learning tool the results of the learning experience must be, in some way, quantifiable. Thus, the *indirect object* of learning should be something that can be tested. The *indirect object* of learning was therefor defined as: *understanding the basics of electric circuit and the most common components.*

The second step in designing the learning experience was to identify the dimensions of variation. Each of the dimensions is intended to teach the student one or more parts of the *object* of learning. The dimensions of variation and what part of the *object* of learning they intend to help the student discern are shown in table 4.1.

The first three dimensions of variation in table 4.1 utilizes *separation*. By separately varying the resistance and the voltage, the students should be able to discern the effects that both have on the current. By connecting and disconnecting a resistor in parallel the student should also be able to discern the differences between series and parallel connections. The fourth is based on the idea of *contrast* [12], since the direction of the current and electrons are opposite.

Table 4.1: Dimensions of variation and what they are intended to teach the student.

| **Varying dimension** | **Concept** | **Object of learning** |
|---|---|---|
| Voltage | The effects of change in voltage on current and power | A |
| Resistance | The effects of change in resistance on current and power | A |
| Series and parallel | The effects of change in connection on the circuit | B |
| Current and electrons | Difference in direction in a circuit | C |

## 4.2 Development

The development phase was carried out in two-week sprints based on the iterative development cycle seen in figure 2.1 and described in section 2.1. Since this phase was a big part of the project each sprint is described in more detail in chapter 5. Instead, this section will only cover the general structure of the iterations in order provide an overall understanding of the development.

### 4.2.1 Description of iterations

Each iteration contains an idea generation phase, development of a prototype and a user-test. The first iteration based its idea generation on observations from the questionnaire, interview and from the scenario. Later iterations based its new ideas on the observations and results from the previous iteration. The contents of the prototype, e.g. assets and features, are listed in each iteration. The issues discovered and general feedback from the users are described in the *test* section of each iteration.

### 4.2.2 Prototyping process

In addition to the main scene, additional scenes were used for Lo-Fi prototyping. Because of the three-dimensional nature of VR, it was deemed ineffective to develop paper prototypes. Instead, new features and ideas were first developed using unity primitives, e.g. spheres, and cubes, in the test scenes. This process made it easier to quickly test, choose and discard new ideas before implementing them in the Hi-Fi prototype.

## 4.3 Verification & Validation

In the final phase of this project the developed learning application was to be evaluated. This was done by performing a user-test with high school students at Lerbäcksskolan in Lund. The purpose of the user-test was to conduct a comparative study with the VR application and traditional learning to collect the data required for analyzing and comparing the learning experience. The test also aimed to evaluate the VR application itself.

In preparation of the user-test, a test plan was drafted. This document is found in appendix C. In this section only parts from the test plan will be mentioned to be able to understand and follow what was performed.

### 4.3.1 Preparations

The participants of the test were planned to be divided into two different groups. In the first group, the teacher would educate the students in the traditional way of teaching, i.e. speaking and drawing on a whiteboard. The second group would instead be using the VR application. The lecture held by the teacher would consist of the same information that could be learned from the application. The idea was that group 2 would be gaining this knowledge using the application instead.

Since one of the goals was to evaluate the VR application itself, a post-test questionnaire was prepared for the second group. With this questionnaire, the goal was to quickly catch the first impressions and thoughts of the interactions in the application immediately after the user-test. Aside from subjective data, it was also determined to collect objective data from the test by preparing an observation protocol. With this protocol, the goal was to make it easier to quickly comment on interesting user interactions and impressions from the students.

To be able to compare the learning situations one final test was prepared that would be answered by all students. The translated version of the final test is found in appendix D.

### 4.3.2 Execution

The user-test took place at Lerbäcksskolan in Lund and began in the morning with the lecture for group 1. This lecture was prepared by the teacher based on the final test questions that the students in both groups would be tested on. The lecture lasted approximately 60 minutes and 13 students took part.

In the afternoon on the same day, the lecture for group 2 with the VR application was performed. One by one, each student entered a classroom where all the VR equipment was prepared and ready for testing. A second Oculus Rift was borrowed from the University. Otherwise, the 90 minutes lecture would not have been enough time to test all the students from group 2.

The test began with a short introduction where the student was told about the VR headset, controllers, and which buttons to use in the application. They were also told to try thinking aloud, i.e. telling their intentions and thoughts while they are interacting. When the student had found a comfortable position for the VR headset it was then time to start the application in Unity. The first instruction to the student was to look around and familiarize themselves with the virtual environment and learning situation. When they felt ready to move on, they were then told to move their focus to the blackboard in the virtual classroom where the two assignments were written. After reading the first assignment out loud they got a couple of minutes to think about the problem and trying to solve it on their own.

In preparation for the test, the time for completing each task had a maximum time limit, (see appendix C table C.4), which determined both when more help was needed by the student and when it was necessary to move on. Due to the time limit for each student, it was required to keep track of the time.

The first assignment was about connecting a circuit using one battery, one light bulb, one switch and one resistor. The goal of this assignment was to make the light bulb shine and adjust the values for the resistor and battery so that the current in the circuit was 4 ampere in total. The steps in this assignment which the student aimed to complete can be seen more in detail in the test plan section C.6.

The second assignment was a continuation of the first one were the student added a second resistor in parallel with the first one. The goal of this assignment was the same as the previous one, make the light bulb shine and adjust the components correctly, but taking the new conditions into account. The steps in detail from this assignment is also written in the test plan section C.6.

When the second assignment was completed the VR session was terminated and the student was told to answer the post-test questionnaire. All students answered the questions on their own before leaving the test while preparations for the next student were made. During the test, observations of how the student performed were entered in the prepared observation protocol. In group 2, 15 students performed the test where each of them got about 10-12 minutes in the VR application to complete the assignments.

# CHAPTER 5

# Development process

In this chapter, the iterations of the development process are described. Each iteration ended with a test with colleagues at Jayway. According to the second principle of UCD (*empirical measurement*) mentioned in chapter 2, the prototypes should be tested by the end-user. The reason for not doing this was that it was not possible to detain a whole class of students, every two weeks, for a user-test.

At these tests, notes were taken about the test subjects interactions with the application and they were told to speak out loud about what they were doing and thinking.

## 5.1 Iteration 1

The goal of the first iteration was set to up the project and scene in Unity, and start implementing the basic assets, models, and user interactions, based on the scenario.

### 5.1.1 Idea generation

Based on research and observations, sketches were drawn for potential assets and features. Ideas from the sketches were chosen, combined or discarded. To spawn objects the user would have a *toolbox* attached to the left controller, similar to a painters pallet (figure 5.1). This UI will from here on be referred to as the *toolbox*. For each component a UI could be opened containing controls for changing the values of the components' (figure 5.2). A *blueprint* would be put on the table to show the user where to put the components (figure 5.3). Two alternative ways of designing the components are shown in figures 5.4 and 5.5. To try and relate the objects to an everyday context, as stated in the learning goal (section 4.1.6), the first alternative was chosen. The *battery* would be created to look like a regular 9V battery so that the student can relate to it. For the same reason, the *light bulb* was designed as a typical light bulb. Based on the sketches virtual 3D models would be created in Blender. The scenario

in section 4.1.5 describes a laboratory situation, and based on this the scene was designed to imitate such a situation. The main goal of the application was to teach electronics, therefore the user must spend as little time as possible learning how to interact with the application.

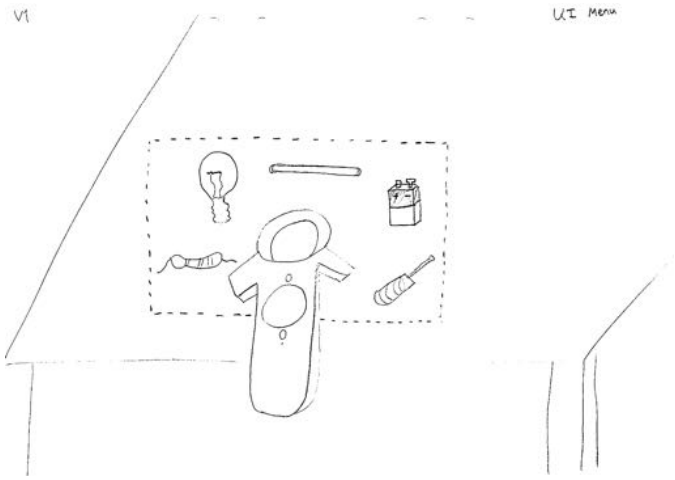


Figure 5.1: A *toolbox* attached to the left controller containing all components

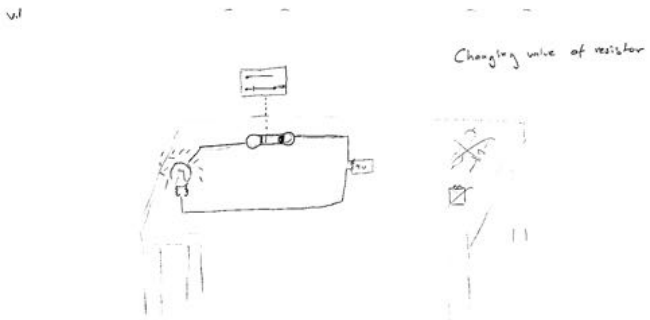


Figure 5.2: UI attached to each component used to set the value of the component.

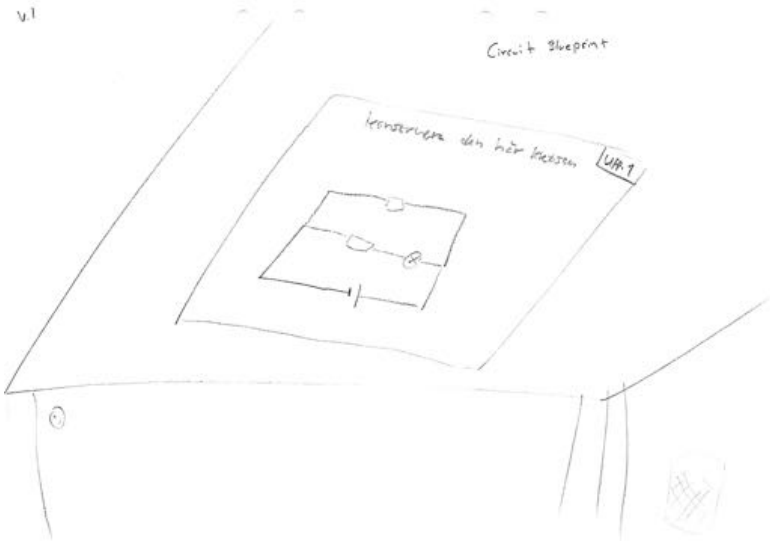


Figure 5.3: A blueprint showing the student where to place the components to complete the assignment.

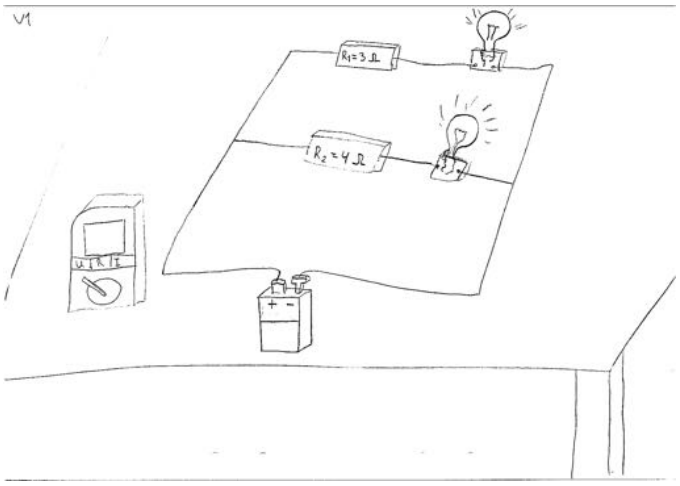


Figure 5.4: Sketch of components and an assignment.

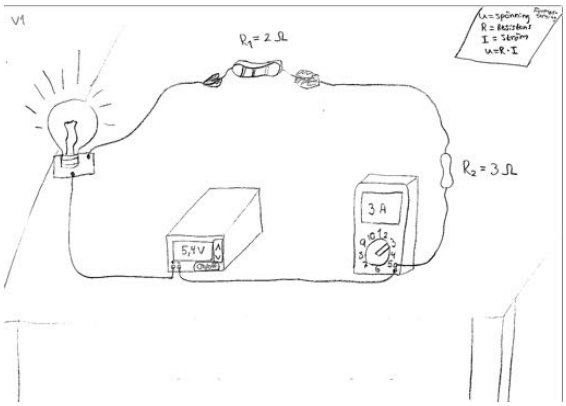


Figure 5.5: Alternative design of components.

### 5.1.2 Prototype

The first prototype contained the following assets and features:

- Assets
  - Table.
  - Battery.
  - Resistor.
  - Crocodile clips and wire.
  - Computer screen.
  - Blueprint for assignment 1.
  - Lamp and socket.
  - Walls, roof and lights.
  - UI for spawning objects (*toolbox*).
  - *Component UI.*
- Features
  - Grabbing and moving objects.
  - Spawning objects from the *toolbox* (figure 5.8).
  - Simple calculation of circuit.
  - Snapping objects in specific places.
  - Highlight boxes showing where objects can be placed.
  - Setting the component's value.
  - Attaching wires to components (figure 5.7).

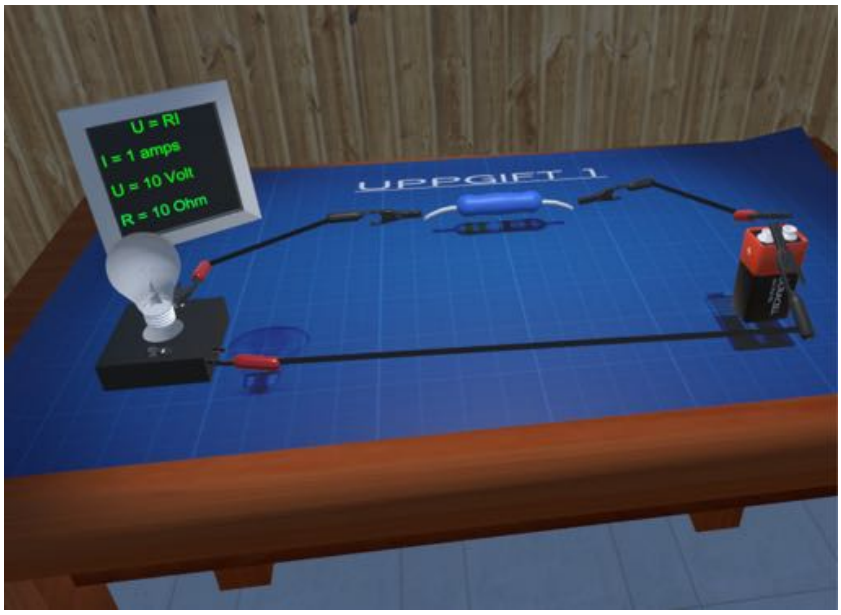


Figure 5.6: A connected circuit with battery, resistor, and light bulb.

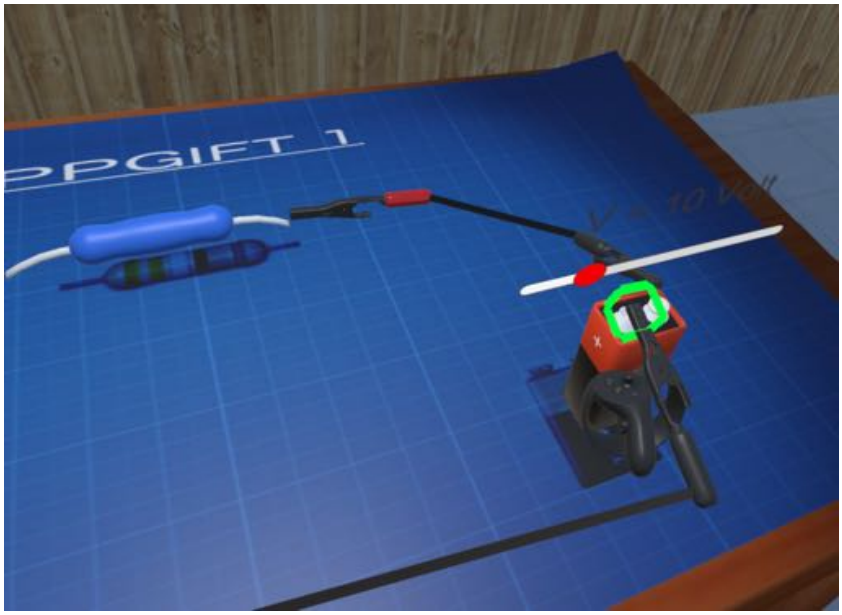


Figure 5.7: Connecting the *clip* to a component and *component UI*.


Figure 5.8: The *toolbox* connected to the left controller and the computer screen showing the components' values.

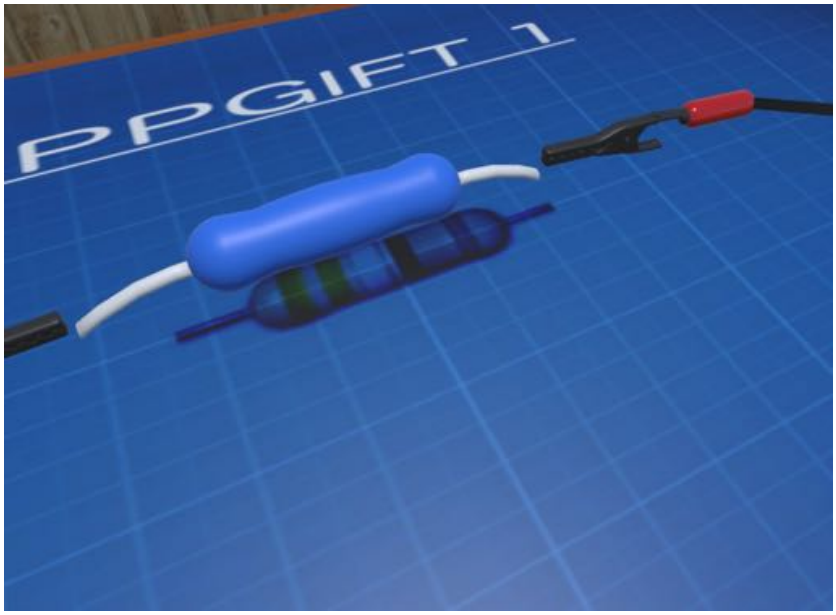


Figure 5.9: A *resistor* connected with two *clips*.

The assignment was to spawn the correct objects, place them in the correct position, connect the wires, and change the values of the components. To spawn a component the *left trigger* was pressed to bring up a UI containing the components. Objects can be grabbed and moved by pressing and holding one of the *grab* buttons. Each component has an attached *component UI* containing a slider and a text field which displays the current value of the component, e.g. voltage. The reasoning behind the *component UI* was that the student would be able to independently vary the resistance and voltage, to see the effects it has on the current. To display the calculation of the current a computer screen was added to the scene. On the screen, the user can track the total resistance, voltage, and ampere. This information was dynamically updated if the user varied either the resistance or voltage. A connected circuit is shown in figure 5.6.

### 5.1.3 User-test

The prototype was tested on nine subjects who were given a minimal amount of initial instructions. After the test the results were divided into three groups `A`, `B` and `C`. Group `A` consisted of the six test subject that performed the test without having seen or used the application before, i.e. they had no prior knowledge of how to interact with the application or perform the tasks. Group `B` consisted of the two subjects that had prior knowledge of the application, i.e. had seen others interact with the application. Group C consisted only of the ninth subject, who tested the prototype after changes had been made. Each of the subjects' interactions were observed and recorded. From this test, 4 major issues were detected.

#### Issue 1: Toolbox and spawning objects

Two out of the six test subjects in group `A` had major difficulties understanding how to spawn objects from the toolbox and needed instructions. Instead of grabbing the objects from the *toolbox* with the right controller they tried to place the entire *toolbox* on the table. Group `B` had no issues performing the same task without instructions. The test subject in group `C` tested this feature after changes had been made and is therefore excluded.

#### Issue 2: Controller buttons and interacting with objects

All test subjects were told which buttons were usable, but not what they were used for. Many of the subjects had difficulties understanding which button to use for grabbing objects. Those who had previous experience with other VR applications had no issue with this.

#### Issue 3: Opening and interacting with the component UI

None of the test subjects realized that it was possible to open a component UI using the *right trigger* without instructions. One of the test subjects noted that

there was an inconsistency in the button mapping when interacting with the component UI slider, since the value is changed using the *right trigger* button instead of the *grab* buttons.

**Issue 4: Lack of feedback when connecting wires**

When connecting the wires to the resistor many of the test subjects had difficulties realizing whether or not the components were connected. Two of the subjects also commented on the fact that, although the wire was connected, there was a visual gap between the *crocodile clip* and the *resistor*. This can be seen in figure 5.9).

## 5.2 Iteration 2

The goal of the second prototype was to address the issues discovered in the first user tests, and continue developing the application.

### 5.2.1 Idea generation

To solve issue 1 new sketches were drawn to generate new ideas to make the *toolbox* more understandable. These sketches are shown in figure 5.10 and figure 5.11. Both sketches were based on the idea that the *toolbox* needed a background to highlight that the components are part of a UI. The round alternative required the user to rotate their hand in a unergonomic way, and it was decided that the flat alternative provided better ergonomics and interactions.

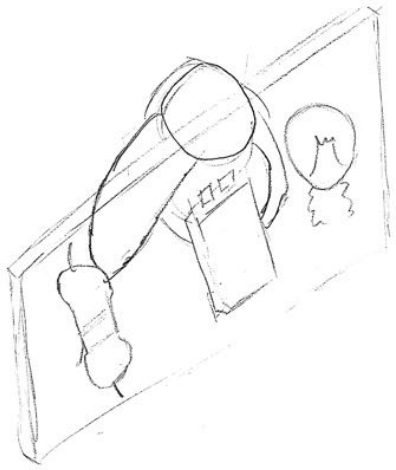

Figure 5.10: Sketch of toolbox with a flat background.

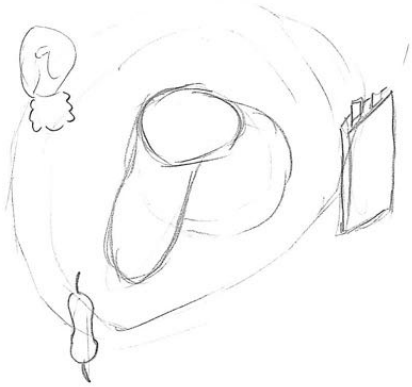

Figure 5.11: Sketch of toolbox with a round background.

Different alternatives to solving issue 2 and 3 using *tooltips* are shown in

figure 5.12 and figure 5.13. *Tooltips* are included in *VRTK* and were tested directly in the prototype. The *tooltips* are only shown when the user looks directly at the controller. However, since the user will most likely look at the controller while placing the components on the table, the *tooltips* will be shown most of the time making them distracting. The second alternative (figure 5.13) was to put the button description on a blackboard, which would make the button layout available to the user at will. The disadvantage of this alternative was that it would leave less space on the *blackboard* for other useful information. The *blackboard* was intended to show instructions for solving the assignment. The idea behind this was that it is natural for a student to refer to the blackboard for instructions and help with their assignments.

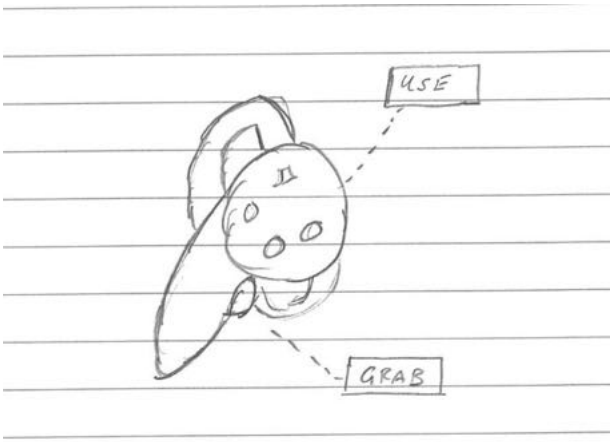


Figure 5.12: Controller *tooltips* showing what action is performed by each button.

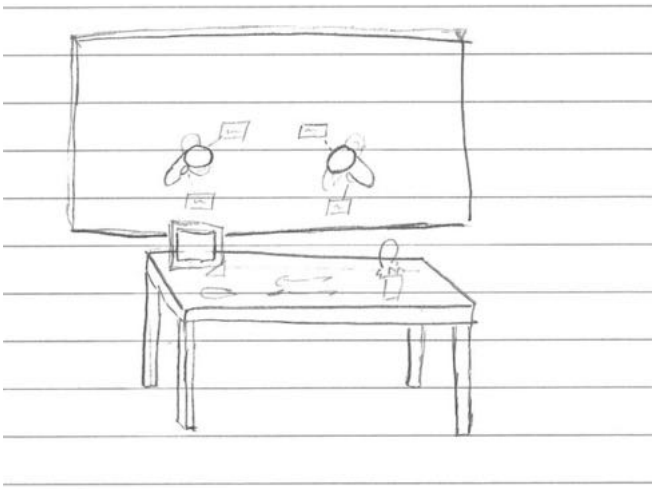

Figure 5.13: Action performed by each controller is shown on a blackboard on the wall in front of the user.

Alternative ways of adding feedback when connecting the *crocodile clips* were discussed, to solve issue 4. Four of the alternatives were: adding an animation that snaps the *clip* in a specific place, adding audio feedback, adding haptic feedback and adding an animation that opens and closes the *clip*. The two animation options were chosen.

### 5.2.2 Prototype

The second prototype contained the following new assets, features and changes:

- Assets
  - Switch. (circuit breaker)
  - Blackboard. (figure 5.14)
- Features
  - *Light bulb* is lit when the circuit is closed.
  - Calculation of power.
  - Open and close animation to *crocodile clips*.
  - Animation when *clips* are connected.
  - Sound effect when placing objects in the correct position.
  - Haptic feedback added when opening and closing *toolbox*.

- Changes
  - Background and frame added to *toolbox*. (figure 5.15)
  - Removed gap between *crocodile clip* and *resistor*.
  - Updated version of the assignment 1 *blueprint* (figure 5.16) .
  - Component value set with *grab* button.
  - Added background for the *component UI* (figure 5.17).

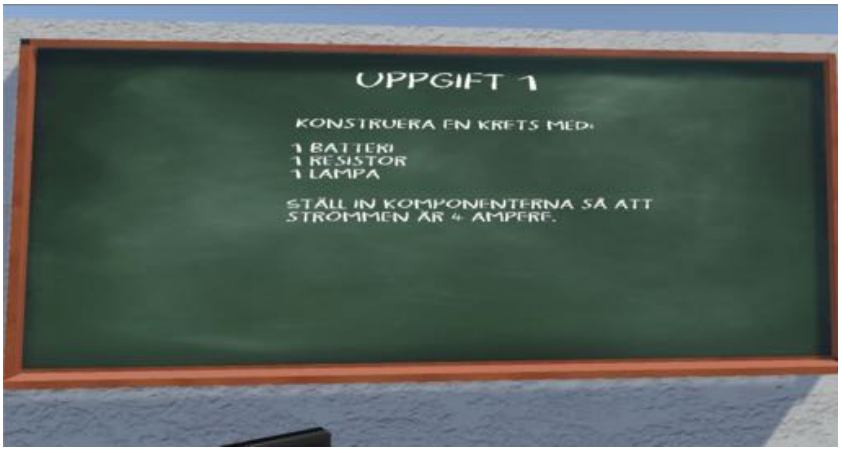


Figure 5.14: Blackboard showing instructions and the assignment.

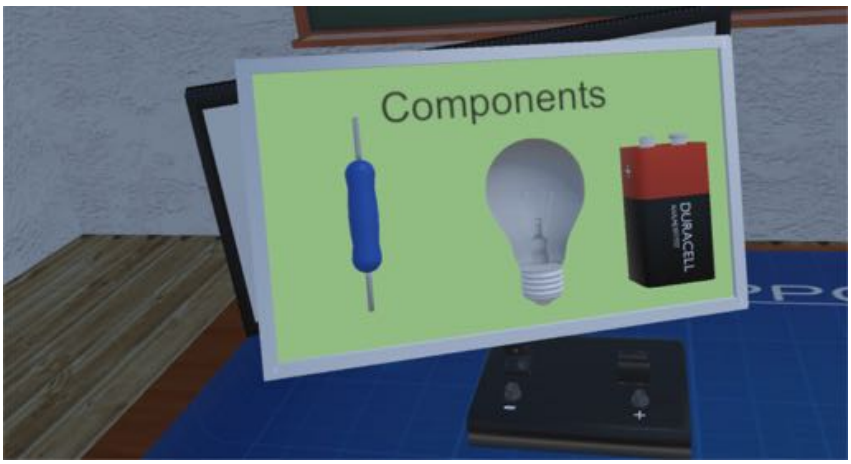


Figure 5.15: New *toolbox* design.


Figure 5.16: A connected circuit.

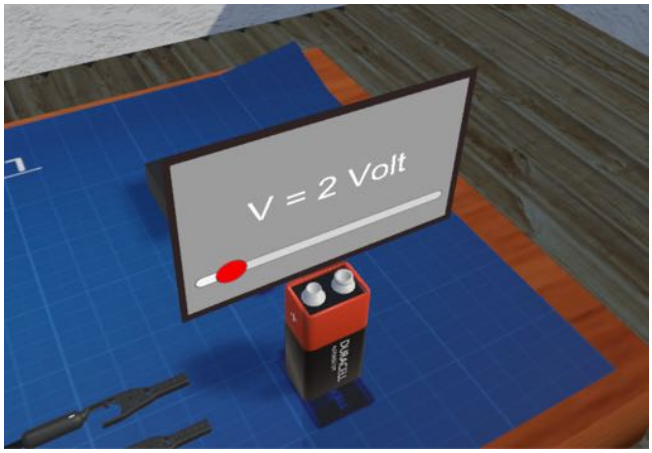


Figure 5.17: The *component UI* used for setting the component's value.

Due to a lack of time *tooltips* were not implemented in this prototype.

### 5.2.3 User-test

Ten people took part in the test and were again divided into three groups. Group `A` consisted of two test subject who had no prior experience with the application. Group `B` consisted of six test subjects who had seen the application being used by other participants. Group `C` consisted of two test subjects who participated in testing the first prototype. As in the first test the users were told which buttons

they should use, but not what function the button had. The assignment given to the test subjects was to spawn and place the correct components, connect the wires, and set the components' values such that the light bulb was lit and the current was set to 4 ampere. The major issues identified during the test were:

#### Issue 1: Disappearing components

In a few instances, a component disappeared when the user closed the *toolbox*. This bug prevented some of the test subjects from completing the assignment.

#### Issue 2: Irretrievable *clips*

When a *crocodile clip* is dropped on the floor the user is not always able to retrieve it, depending on where it landed. This bug also prevented completion of the assignment for some of the test subjects.

#### Issue 3: *Clips* can move and tip objects

In some instance when a *clip* is connected to the *battery*, the *battery* tips over. In a similar manner, when connecting *clips* to the *resistor*, the *resistor* is pushed sideways.

#### Issue 4: Opening the *toolbox*

The issue of users placing the entire *toolbox* in the table did not reappear, however all test subjects in group `A` had issues discerning how the *toolbox* is opened. Test subjects in group `B` and `C` did not have this issue.

#### Issue 5: Lack of feedback when connecting *clips*

Based on comments from the test subjects it was still not clear that the *clips* were connected correctly, i.e. the animations added did not provide enough feedback. There was also a large gap between the *clip* and the *battery*, which made it difficult to see if the *battery* was actually connected (figure 5.16).

#### Minor issues and comments

In addition to these issues some minor problems and comments from the test subjects were noted. These include:

- The wires are "one-way" directional, which is not realistic.
- Two test subjects in group `B` insisted on using the *trigger* to grab objects.
- Some test subjects tried to place the *light bulb* on the image on the *blueprint* instead of in the *socket*.

### 5.2.4 Improvements

User interactions with the *toolbox* saw major improvements in the second prototype, since all test subjects understood that the *toolbox* was an intractable UI. As mentioned above, the animations for connecting the *clips* did not provide enough feedback to the user. Additional feedback could possibly improve the interactions further. Knowing which actions are performed by each button remained an issue for the test subjects in group `A`. However, the test subjects who were familiar with the button layout were able to interact with the application mostly without issues. Adding the *blackboard* with instructions to set the components' values made this feature more apparent, but there was a lack of signifiers as to how the user opens the *component UI*.

The fact that the *light bulb* was lit and that the intensity of the light changed when the user adjusted the components' values clearly signified for the user that they were performing the correct actions.

## 5.3 Iteration 3

The results of the second prototype test showed that there was a general lack of feedback when interacting with the application. According to the interview with the teacher, feedback is important for the students, especially if the subject is new to them. The goal of this iteration was to enhance the feedback, resolve the software issues, and enhance the immersion of the VR experience.

### 5.3.1 Idea generation

It became obvious in the tests that more feedback was needed when connecting the *clips*. For this prototype both audio and haptic feedback would be added by extending a VRTK script. The controller would vibrate while holding the *crocodile clip* in the correct position and upon releasing the *clip* a sound would be played to indicate that the clips is placed in a correct location.

The highlight boxes which were supposed to indicate where *crocodile clips* can be connected had previously not worked for the *battery* and *resistor*. This was caused by an optimization feature in VRTK, which disabled a script attached to the object when that objects was idle. This issue was therefore resolved by simply removing the optimization feature. This made it more apparent where the *clips* could be attached.

A new version of how to design the *tooltips* is shown in figure 5.18. This design was similar to the sketch in figure 5.12, however the new version only shows what functions are performed by the trigger. By process of elimination the user should be able to understand which buttons are used for grabbing objects. To ensure that the *tooltips* does not distract the user a script was written which hides the *tooltip* when grabbing objects.

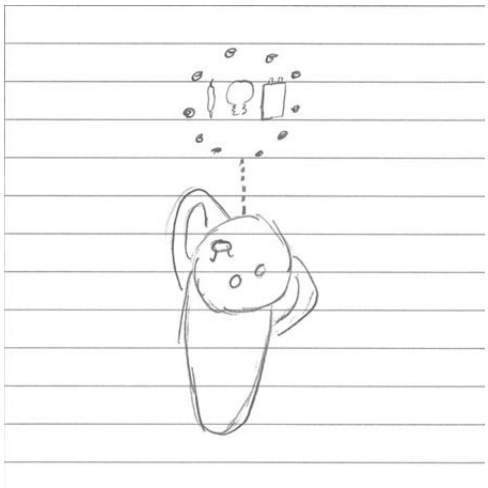

Figure 5.18: A *tooltip* showing the action performed by the *left trigger*.

### 5.3.2 Prototype

Issue 1 in the previous iteration was caused by incorrect extension of a VRTK script, and was fixed by overriding an additional method.

To solve issue 2 a script was added that deletes the dropped *crocodile clamp* and spawns a new one on the table. *Crocodile clips* were also set to not collide with each other, which was one of the factors that caused the issue. Because of this change the probability of the issue occurring decreased.

The third prototype contained the following new assets, features, and changes:

- Assets
  - Lamp hanging above the table for better lighting.
- Features
  - *Clips* do not tip over or move components.
  - *Clips* respawn if dropped on the floor.
  - Electrical *buzzing* sound when the circuit is closed.
  - *Tooltip* for right and left *trigger* button (figure 5.20).
  - Highlights on the *battery* and *resistor* where the *clips* are connected. Only shows if the user holds a *clip* close to a correct *snapzone* (figure 5.21).
  - The current is animated in the wires when the circuit is closed.
  - Haptic and audio feedback added when a *component* or *clip* is close to a *snapzone*.

- Changes
  - Removed the *light bulb* and *switch* images from *assignment 1* paper.
  - New room environment (figure 5.19).
  - Improved grab interaction for *clips*.
  - Less reflection on the *blueprint*.
  - Changed how the *clips* are attached to the *battery* to make it clearer if they are connected or not (figure 5.22).

Figure 5.19: Wide angle view of the *scene*.

Figure 5.20: Controller *tooltips*.

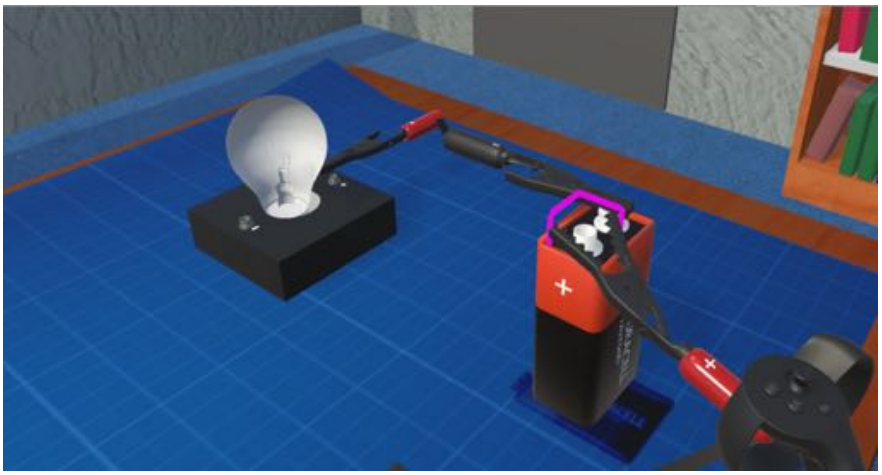

Figure 5.21: Highlight zone on the *battery* that shows where to place the clip.

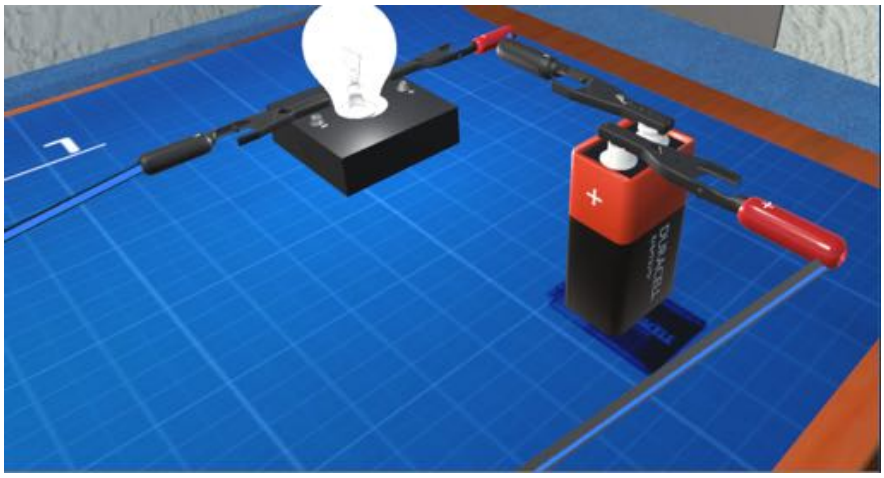

Figure 5.22: Connected circuit with a lit *light bulb* and better *clip* connection (compare with 5.16).

### 5.3.3 User-test

Five test subjects took part in the test. One of the test subjects had not tested the application before and one had seen others use it. The other three had used the application before.

All the test subjects were able to complete the assignment and encountered no errors, which was a major improvement compared to the previous test. Two of the test subjects did not know or remember how to open the *toolbox*, and they both used the *tooltip* to find out which button to use. Two test subjects connected the circuit without the *switch*, which theoretically should work since the circuit is closed. However, because of how the script that calculates the current is written, the circuit is not registered as closed without the *switch*. The script was written this way so that students would be forced to use all components. Three of the test subjects needed help to open the *component UI*. The two major issues identified were:

#### Issue 1: Opening the component UI

The *tooltip* showing which button is used to open the *component UI* helped some users identify which button they should use, however they did not understand that they needed to touch the component for it to open.

#### Issue 2: Setting the value of components

All test subjects had issues grabbing the slider that sets the component's value in the *component UI*.

**Comments**

The following are comments from the test subjects:

- The *light bulb* is lit before the current animation is complete. The test subject suggested that the direction of the current could be showed with arrows instead.
- Besides the value of the current displayed on the computer screen, there is no other indication that the assignment is completed.

### 5.3.4 Improvements

The most important improvement in iteration 3 was that all test subjects were able to complete the assignment. In the previous iteration half of the test subjects were unable to complete the assignment due to software errors.

One of the goals of iteration 3 was to improve the feedback. None of the test subjects had issues knowing if they connected the circuit correctly, which was a major improvement over the last iteration. The left controller *tooltip* proved useful when trying to understand how to spawn components, however the right controller *tooltip* did not have the same effect.

## 5.4 Iteration 4

The goal of iteration 4 was to implement additional features related to the learning goals.

### 5.4.1 Idea generation

One of the learning goals was to understand the direction of the current and the electrons in an electric circuit. In the previous iteration the direction of the current was implemented by animating a blue line through the wires once the circuit was closed. This animation was however only played once, and was therefore easy to miss. Based on one of the comments from the last test a new design was drawn using an arrow to show the direction of the current. This sketch also included a sphere showing the flow of electrons in the circuit (figure 5.23).

Another learning goal was series and parallel connections, which had been implemented in an experimental scene in an earlier iteration. To avoid having to switch between scenes when using the application, a new scene would be created in which it is possible to connect a circuit similarly to the original scene, as well as connecting two resistors in parallel. This also makes it possible to vary the type of connection in real-time by simple connecting and disconnecting one resistor. This change would mean that the *blackboard* need to be redesigned in order to account for the two different assignments (figure 5.24). Circuit diagrams were also added to the blackboard. The idea behind this is that the students will learn the symbols for each components using spatial memory.

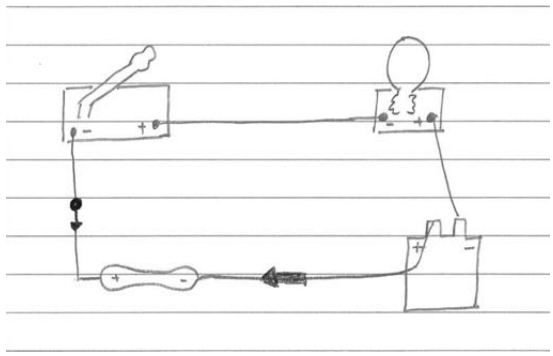

Figure 5.23: An arrow and a sphere flowing through the wires showing the direction of the current and the flow of electrons.

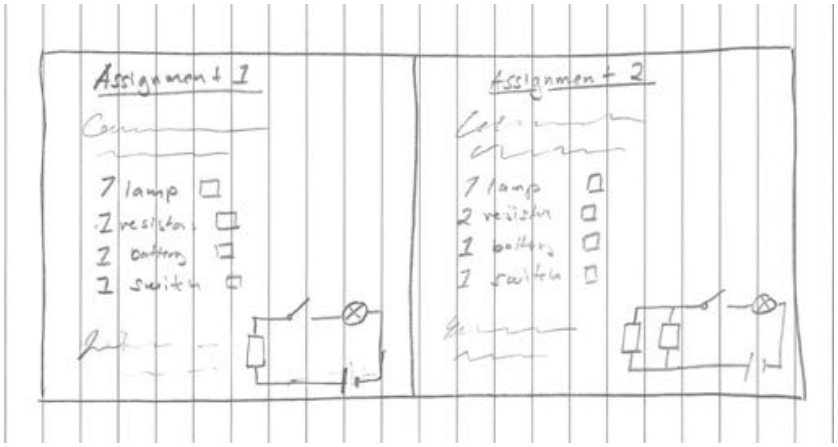


Figure 5.24: Sketch of blackboard showing two assignments with circuit diagrams.

To make it easier to set the values of the components the *slider handle* would be made larger.

### 5.4.2 Prototype

The prototype contained the following new features and assets:

- Assets
  - A new *resistor* for parallel connections.
- Features

  - The possibility to connect a *resistor* in parallel (figure 5.25).
  - The direction of the current is displayed with an arrow (figure 5.27).
  - The flow of electrons is displayed with a sphere (figure 5.27).

- Changes
  - The *computer screen* now shows the calculation of the power.
  - The *blackboard* displays which components are connected correctly using check marks, which update dynamically (figure 5.26).
  - The *blackboard* now shows two assignments with circuit diagrams (figure 5.26).
  - The slider handle in the *component UI* was made larger and easier to grab.
  - The color of the text showing the current amperes is green when the assignment is completed.

The test assignment for this prototype was divided into two assignments. First, the user connects the circuit and sets the components' values in the same way as previous tests. Then the user adds another resistor to create a parallel connection, and resets the values.

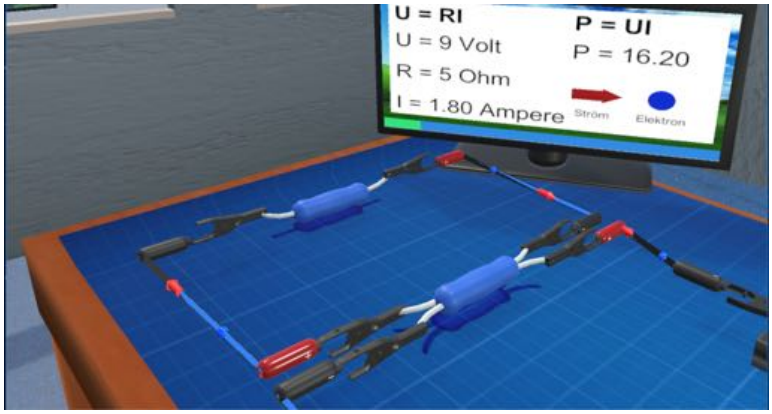


Figure 5.25: Resistors connected in parallel.


Figure 5.26: *Blackboard* showing two assignments with circuit diagrams.


Figure 5.27: Arrows and spheres showing the direction of the current and electrons.

### 5.4.3 User-test

The test was carried out with seven participants, who were divided into the same three groups as in previous tests. Group `A` and `B` consisted of three test subject each, and group `C` consisted of one test subject. All test subjects were able to complete both assignments with few issues. Some of the test subjects tried to connect the wires incorrectly but managed to discern the correct action by experimenting with the application. A majority of the test subjects looked at the assignments on the *blackboard* before starting to interact with the components. No major issues were found as a result of the test.

**Minor issues and comments**

- *Light bulb* is too bright on max power, which made it hard to read the text on the *blackboard*.
- Resistors that are respawned after being dropped have the *component UI* facing the wrong direction.
- Some users commented that they were not sure whether or not the assignments were completed.
- The *socket* can be moved if dragged with the *light bulb*, which can potentially make connecting the wires difficult.
- Highlight zones should be green instead of purple.
- Some user had issues knowing how to use the *switch*.

### 5.4.4 Improvements

The major improvements to the application in this iteration was the implementation of additional learning goals, i.e. parallel connections and direction of current and electrons. The animated arrows was a clearer way of representing the direction of the current.

## 5.5 Iteration 5

The goal of this iteration was to address some of the minor issues and comments from iteration 4 to ensure that the application was ready for the final user-test with students.

### 5.5.1 Final prototype

Since iteration 5 was to be the last iteration before the user-test no new features were added. The highlight zone color was changed to green for consistency. To better signal how to use the *switch* handle, the color of the knob was changed to red (figure 5.28).
The formula for how resistance is calculated in serial and parallel connections was not present in the application. This was added to the *blueprint* below the *resistors*. The formula changes depending on whether there is only one resistor connected (figure 5.29) or if there are two resistors connected in parallel (figure 5.30). This variation is intended to help the student discern the different ways of calculating the total resistance.

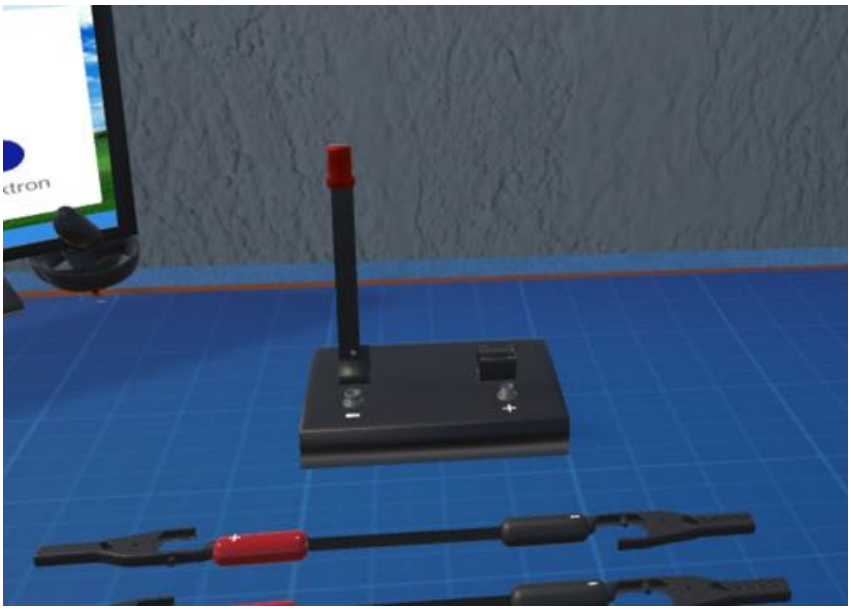

Figure 5.28: The new color of the *switch* handle to make it easier to understand that it is interactable.

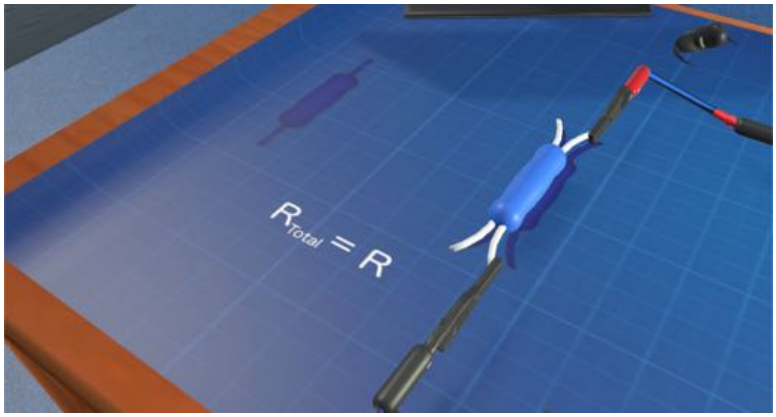


Figure 5.29: Formula for calculating the resistance with only one *resistor*.

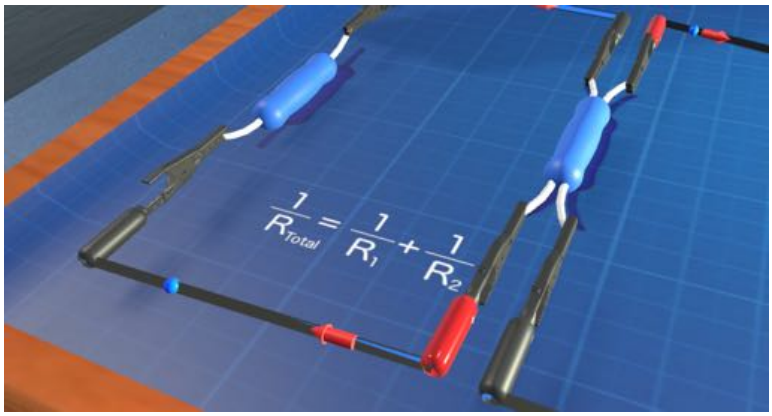


Figure 5.30: Formula for calculating the resistance with two *resistors* connected in parallel.

# CHAPTER 6

# Results

In this chapter the result derived from the project process, explained in chapter 4, is presented.

## 6.1 Questionnaire 1

The first questionnaire was sent out as a pilot test at the start of the conceptual phase of this project. There were two answers collected from teachers at *Linnéskolan*. All the questions from this questionnaire are listed in appendix A and the result can be seen in the list below.

- Q1: Which school do you teach at?

  R.1 Linnéskolan

  R.2 Linnéskolan

- Q2: Which field do you teach in?

  R.1 Chemistry, Physics, Biology, Engineering

  R.2 Chemistry, Physics, Biology

- Q3: Which parts in your field do you have experience of students having difficulty, or is more difficult than other parts, to understand/remember? Please describe this part.

  R.1 Areas that are hard to visualize by drawing and then by this picture interpret theoretical concepts.

  R.2 To understand and visualize bigger concepts.

- Q4: Why do you think students experience this part to be more difficult and hard to grasp when it comes to learning it?

  R.1 The translation between abstract and theoretical concepts without something more concrete that keeps the new obtained knowledge.

R.2 It requires maturity and practice.

- Q5: Do you use any tools for visualization in education today? If yes, which tools?

  R.1 Powerpoint, Smart board, Computer program

  R.2 Projector

- Q6: What is your opinion of introducing more technology in school? Do you think it would increase students engagement and ease education when it comes to learning?

  R.1 Yes, I believe that proper use of technology, movies, animations, test programs etc. will make many things easier and more fun and also more "up-to-date" with the rest of their lives, which are becoming more and more digitized.

  R.2 Yes, as a compliment. But absolutely not as a solution on every problem.

## 6.2 Questionnaire 2

In the second modified questionnaire seven answers from teachers were collected. To make sure that not all answers came from teachers working at the same school the teachers were required to submit which school they worked at. This ensured that the data gathered was not based on a systemic issue at a particular school. Which schools is however not of any importance further on and is omitted in the representations of the data below.

- Q2: Which field do you teach in?

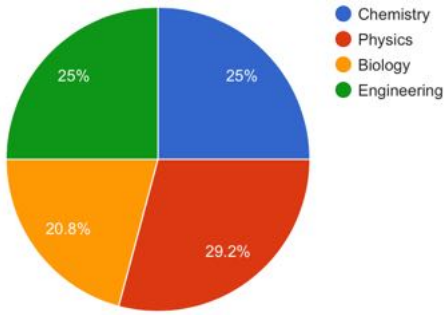


Figure 6.1: Result of the different teaching areas collected.

- Q3: Which parts in your field do you have experience of students having difficulty, or is more difficult than other parts, to understand/remember? Please describe this part.

R.1 Atom and nuclear physics, Energy

R.2 Chemical formulas

R.3 The field engineering

R.4 Electro chemistry, mechanics, Genetic.

R.5 Atom models, electricity

R.6 The students find it hard to understand things that are not visible to the human eye and that happens on molecular level.

R.7 Electricity

- Q4: Why do you think students experience this part to be more difficult and hard to grasp when it comes to learning it?

R.1 It is in some way too abstract for the students to understand

R.2 For example how to balance a chemical formula and understand that it should be equal number of atoms on both sides. It becomes a bit abstract for them even though I show them with physical models.

R.3 We teachers have not been educated in the field of engineering.

R.4 .

R.5 The hardest part is that they can not relate the information they learn to every day life.

R.6 .

R.7 It is hard to get every student involved. Missing decent lab material equipment.

- Q5: Do you use any tools for visualization in education today? If yes, which tools?

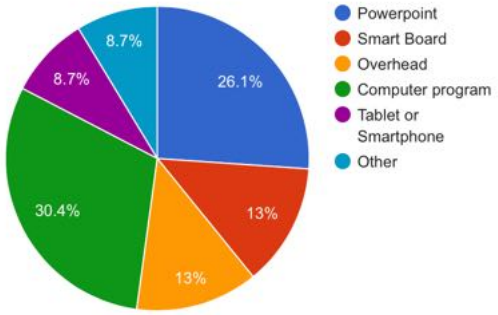


Figure 6.2: Result of which tools in education are used by the teachers.

- Q6: What is your opinion of introducing more technology in school? Do you think it would increase students engagement and ease education when it comes to learning?

  R.1 Above all, more teachers are needed that are educated to teach in the field of engineering.

  R.2 I am absolutely positive. Overhead is only used in demonstration of a special reaction that are quite risky and therefore needs some safety distance.

  R.3 Yes, I think.

  R.4 I think that more technology in school would increase the engagement among students e.g. wireless camera/assets to a Smart Board.

  R.5 Students like computers as aiding tool in education but it must exist relevant programs to get them interested.

  R.6 I am positive to everything that helps students and ease their way of learning and acquiring knowledge.

  R.7 Both Yes and No. You should not introduce parts in education that does not increase the quality. Sometimes it feels like everyone thinks that IKT is the solution but it has not changed the quality in education. Students thinks it is fun to use computer, iPhone, iPad etc. On the other hand it is good for students that needs additional help in understanding.

## 6.3 Interview

The full transcribed interview can be found in appendix B. A compiled version of the interview is shown in the list below.

- Series and parallel connections: *How the current, resistance and voltage changes.*
- Capacitors and resistors: *How they work.*
- Resistance: *Different ways of explaining resistance.*
- Diodes: *How the current flows through diodes.*
- Circuit diagrams: *Can look different but are the same.*
- Light bulbs: *How they work.*
- Direction of current and electrons.
- Lab material: *Broken components makes the students question their understanding of the subject.*

- Traditional vs. Digital: *Digital offers better feedback which helps students understand if their thought process is correct.*
- Learning goals:
  - *Curriculum.*
  - *Electrical safety in the home.*
  - *Creating interest for physics and engineering.*

## 6.4 Post-test questionnaire

In the validation and verification phase of this project the students in group 2 answered a post-test questionnaire immediately after the test. In this section the result from this questionnaire can be seen.

- Q1: Do you think using Virtual Reality is fun when it comes to learning electronics?

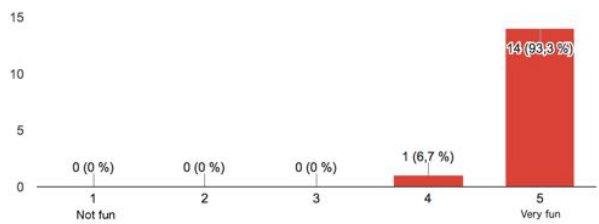


Figure 6.3: Result of post-test questionnaire 1.

- Q2: Do you think it was easy to understand what your assignment was?

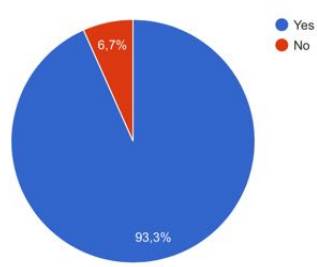


Figure 6.4: Result of post-test questionnaire 2.

- Q3: Do you think it was easy to understand how and what you needed to do to solve your assignment?

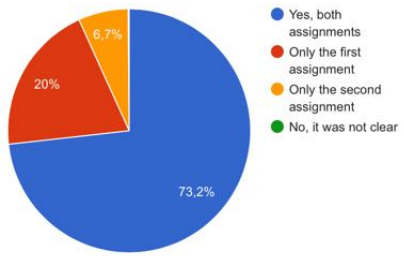


Figure 6.5: Result of post-test questionnaire 3.

- Q4: Was it easy to understand when you had completed your assignments?

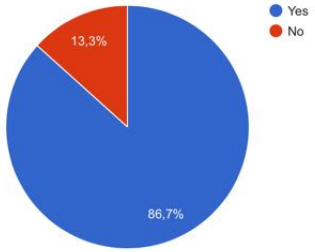


Figure 6.6: Result of post-test questionnaire 4.

- Q5: Do you think it was easy to understand how to use a Virtual Reality headset and interacting with the controllers?

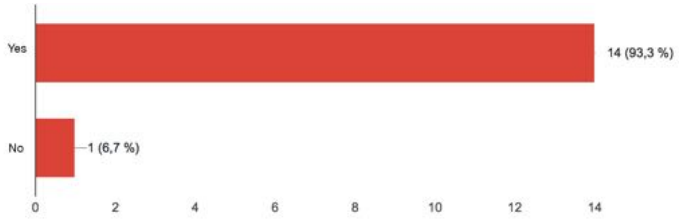


Figure 6.7: Result of post-test questionnaire 5.

- Q6: What do you think was the best or worst part of using Virtual Reality?
  - It was easier to understand.

  - It is really great because it is fun and educational at the same time and this is something new for everybody. But the equipment is unfortunately very expensive.
  - The best part was that it was so funny and I do not think that there was anything bad with it at all.
  - The worst part was that the vision was blurry.
  - Do not know.
  - I think it was extremely fun to use it and it felt more cool than in reality. The best part was that you could feel the vibrations e.g. when you grabbed something. Another thing was that it did not occur any lag even though some bugs appeared.
  - I think it was really funny and that it was a different way of learning the new things.
  - The best part was to have fun and be learning at the same time.
  - Very cool and interesting.
  - The best part was to enter another room.
  - The best part was that it felt like entering a completely different world.
  - It was fun to learn new things, and I do not think anything specially was bad.
  - Nothing was bad, but it was very funny to test something new.

- Q7: Do you have any other thoughts or comments of using Virtual Reality in school or the application itself?
  - Good in engineering and to do practical work without the risks.
  - This is extremely funny and I really would like to try it again.
  - It would be fun to do like this in school.
  - Not really.
  - I am thinking of buying my own VR headset but probably not like this one because it is surely too expensive.
  - It would be really fun to use VR in school, because it is very modern and special.
  - I think it would be cool if everybody was able to test it but it would probably be too expensive.
  - No =).
  - Extremely fun way of teaching.
  - veeeeery fuuunn! ;)))))).

## 6.5 Final test results

The results of the final test are shown below. Group 1 consisted of 13 students, whereof 12 took the final test. Group 2 consisted of 15 student, whereof 14 took the final test. The last question in the final test is not included in the calculation of the average, due to it asking for the students subjective opinion.

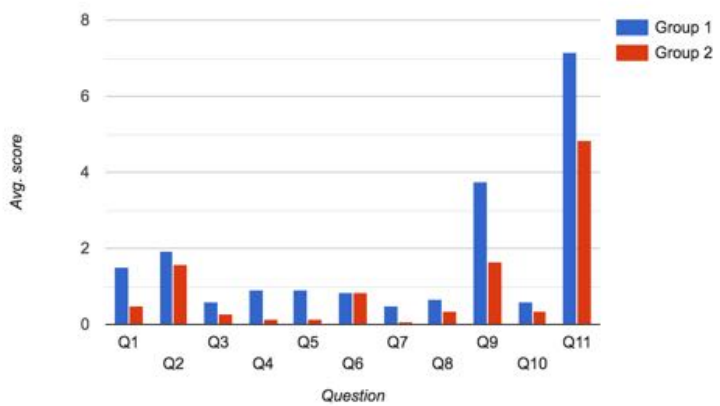


Figure 6.8: Average score of each question for both groups.

In the table below the data collected from the final test is presented. The maximum score on the final test was 18. The two last columns show the differences in average and mean score between group 1 and 2. Positive values imply that group 1 scored higher than group 2.

Table 6.1: The average and mean score of both groups for each question in the final test.

| | **Group 1: Average score** | **Group 2: Average score** | **Group 1: Mean score** | **Group 2: Mean score** | **Diff in average** | **Diff in mean** |
|---|---|---|---|---|---|---|
| **Q1** | 1.5 | 0.5 | 1 | 0.5 | 1 | 0.5 |
| **Q2** | 1.92 | 1.57 | 2 | 1 | 0.35 | 1 |
| **Q3** | 0.58 | 0.29 | 1 | 0 | 0.29 | 1 |
| **Q4** | 0.92 | 0.15 | 1 | 0 | 0.77 | 1 |
| **Q5** | 0.92 | 0.14 | 1 | 0 | 0.78 | 1 |
| **Q6** | 0.83 | 0.86 | 0 | 0 | -0.03 | 0 |
| **Q7** | 0.5 | 0.07 | 0.5 | 0 | 0.43 | 0.5 |
| **Q8** | 0.67 | 0.36 | 1 | 0 | 0.31 | 1 |
| **Q9** | 3.75 | 1.64 | 4 | 1.5 | 2.11 | 2.5 |
| **Q10** | 0.58 | 0.36 | 1 | 0 | 0.22 | 1 |
| **Q11** | 7.17 | 4.86 | 7.5 | 4.5 | 2.31 | 3 |
| **Total** | 12.58 | 6 | 12.5 | 6.5 | 6.58 | 6 |

# CHAPTER 7

# Discussion

In this chapter, the methods used to develop the application, the results of the user-test, and future research are discussed.

## 7.1 The VR learning experience

The hypothesis of this thesis was that Virtual Reality could engage students and provide a good learning experience. Based on the results of the first question in the post-test questionnaire (figure 6.3), it is obvious that the students enjoyed using VR as a learning tool. In the open questions (questions 6 and 7) the students shows enthusiasm for both VR and the learning experience, saying for instance:

> "The best part was to have fun and be learning at the same time."

The majority of the open questions were positive towards VR in learning, and there were some interesting comments from the students. One student wrote that:

> "Good in engineering and to do practical work without the risks."

This comment mentions one of the advantages of VR, namely that experiments can be performed without the risks. Not having to consider the potential risks of a lab or learning situation makes it possible for the student to experiment freely. The results from the post-test questionnaire also showed that a majority of the students understood what their assignment was (figure 6.4) and how to complete the assignments (figure 6.5). The results from the post-test questionnaire are enforced by the observation protocol.

The last question in the final test (see appendix D) was an attempt to quantify the student's engagement in an objective way. However, as can be seen from question 11 in table 6.1, group 1 responded that they found the subject to be

more interesting. The teacher mentioned that group 2 became quite discouraged when taking the test since they felt that they had not learned enough about the subject. The results from the post-test questionnaire are, therefore, a better measurement of the student's engagement.

One of the advantages of VR is that the user is isolated from the world around them, making it easier to concentrate on the tasks at hand. This was observed in many of the test subjects in the user-tests who, although they enjoyed the experience, were extremely concentrated when trying to complete the assignments. However, this isolation can be seen as a disadvantage as well. Isolating students from each other removes the social aspects of school and it also removes the experience of learning as a group. It also makes it difficult for the students to either take notes or make calculations with pen and paper. To take advantage of the positive aspects of the isolation that VR creates, the learning situation could as an example be constructed in the following two ways:

- Short VR experiences as a complement to other learning activities; or
- Collaborative VR experiences where one student uses the VR application and one or two other students take notes, do calculations, and discuss the assignments with the VR user.

These two examples would utilize the advantages of VR, without infringing on social aspects or removing the possibility of taking notes.

When the user-test had been performed it became obvious that the students had too little time with the application, i.e. their *acquisition* phase (see section 2.2) was very short. While the students in group 1 had approximately 60 minutes to absorb all the information needed to reach the learning goals, group 2 had only 10 minutes. The reason why the test was that short was that the teacher wanted all students to try the application so that some student were not left out. On average, students in group 1 performed better on all questions from the final test, except for question 6 (see D.1.6). As can be seen in table 6.1, group 1 had an average score twice as high as group 2. The only question where group 2 scored better, however with a small margin, was the question regarding the direction of the current and electrons. One of the hypotheses of the thesis was that this type of abstract concept would be better visualized in VR than with traditional learning material. It should also be mentioned that group 2 were able to score slightly better on this question although they only had 10 minutes with the application, as opposed to the other group's 60 minutes lecture. This would indicate that the way this concept was visualized made it easy to remember. It should be mentioned that for each of the questions in the final test, there was at least one correct answer from a student in group 2. Based on the fact that the students had very little time, that they had no previous knowledge about electronics or electronic circuits, and still were able to correctly answer some of the questions, the results are quite satisfactory. One student in group 2 scored 10 out of the total 18 points, which considering these

factors is very good. This score is only 2.5 points away from the mean score of group 1. If the students had received a short introduction to the basics of electronics and electric circuits or if they had more time, the results might have been very different. If there had been a possibility of testing the application on more classes, a more thorough comparison could have been made. For instance, in addition to the two groups in this project, the third group would have had a theoretical lecture first and then VR lab, and a fourth group would have the same lecture and then use traditional lab material.

Another aspect of learning to consider is the retention of knowledge over time. This ties back to the *temporal facets* described in section 2.2. The students in the user-test were tested on what they had learned, i.e. *making use of*, the day after the lecture. The results might have been very different if the *knowing* phase was longer, e.g. the final test was taken days, weeks or months after the lecture. It is possible, for example, that the way the direction of the current and electrons was visualized is easier to remember.

## 7.2 Interaction design for VR

When it comes to creating a Virtual Reality experience from an interaction design perspective there are important aspects that have been covered in this project. Firstly, designing virtual objects in a virtual environment can be done with natural mapping, i.e. a natural relationship between interaction and outcome from such action in the virtual world. In the developed VR application a user was able to grab, lift, and place various electrical components on a table and connect them together in a circuit using crocodile clips. These actions are all very similar compared to how this would have been done in the real physical world. When it comes to the actions themselves, by actually moving VR controllers that have sensors to follow the user's hands, they are also more natural than other techniques, e.g. touch, keyboard, and mouse. In the result from the post-test questionnaire in figure 6.7 the ease of using a VR headset and controllers is confirmed by the students.

The possibility of creating a virtual environment removes many physical limitations that exist in the real world, e.g. lifting heavy objects, being able to see things that are not visible to the human eye, and creating animations. The power of visualization in VR is something that really can enhance a user's experience. In the application, the advantage of visualizing abstract concepts in VR can be seen in a couple of features e.g. animation of the current, the direction of current in shape of arrows, and electrons flowing through the wires. Compared to a traditional learning situation, whether it is a lecture held by a teacher or a lab with real electrical components, it would not be as interactive and visual as in this application.

With a UI that contains much information presented to the user, one aspect that needs to be considered in interaction design is cognition. Cognition could be described as specific processes that include e.g. attention, perception,

memory, and learning [8]. These processes are dependent on each other and are important to think about when presenting information to the user. With VR it is possible to dynamically change what, how, and when the information should be presented. In the application the possibility to see which values the electrical components have, visualized on the computer screen, requires the user to complete the connection of wires to all components. Otherwise this information cannot be seen by the user and does not distract them. Another example is the *toolbox* used for dragging out new components and the *component UI* for adjusting the components' values. All these examples take the cognition aspect in consideration in order to not confuse the user with too much information at the same time. An example in the application that presents the information at the right time is when calculating the total resistance. The images on the blueprint change depending on the type of connection. When varying the type of connection, the formula for how to calculate the total resistance also varies (figure 5.29 and 5.30). This does not only give the user the information *when* it is needed, but also spatially *where* it is needed.

There are not only advantages of using Virtual reality in interaction design. The advantage of the mentioned ability to dynamically present information at the right time for the user could also be seen as a disadvantage. Having functionality which is not visible to the user at all times, could be considered as hidden features. In the application, the two most important functions that act like this is opening the *toolbox* and *component UI*. Due to their invisibility, it becomes more difficult for the user to know what to search for or how to use them. The option of having something visible for the user or present it when needed is a challenging decision and might affect the user negatively. In the development phase of the application, these two options were both tested by colleagues at Jayway to find the best solution. The final result of keeping them hidden made the user less confused since there was plenty of other information visible already. However, to make the user aware of the hidden functions this was instead compensated by having smaller *tooltips* pointing at the corresponding buttons on the controllers. Another reason for keeping them hidden was that the users that had tested the application before had much less problem of finding these functions in the following tests.

Designing an intuitive experience in Virtual Reality is an iterative process, as in many other software projects that aim for a good user experience. By using the user-centered design process, the importance of early focus on the end-user and understanding of the context can be achieved during the development. In this thesis, the data gathering in the conceptual phase was critical to find an area where students have difficulties, and the underlying causes for it. The questionnaires and interview were a great approach to collect the required data from the teachers, and to be able to make a choice of what type of VR application to create that could enhance the learning experience for students. By asking these questions early in the project, it was certain that the application was developed based on real teacher opinions and experiences from the start. This was neces-

sary information to be able to create a VR application that aimed to suit both teachers and students. As one might have realized reading this report, there were actually two end-users in this project. This condition made the design process more difficult since the application had to cover the needs of both the teacher and the student.

With the creation of a learning application, it was of the greatest importance to involve pedagogy and variation theory throughout the design process. No matter how good the visual representation of the virtual objects is, this would never be seen as a learning application without understanding the basics of how people learn. With the final result in mind, there are many design decisions that were made based on variation theory, and the application would definitely have looked different without taking this aspect into consideration. In this project, to mention one big functionality that shows this is, the possibility for a user to vary the values of electrical components, e.g. voltage on a battery. By varying the voltage in an electrical circuit the user was able to discern differences in variation of that particular property and the result of that action. This example highlights one of the biggest advantages of combining variation theory with Virtual Reality, which is instant feedback. In VR it is possible to add feedback in a couple of ways, e.g. sound, light, visualization, vibration, etc. With help of these, the user experience can be enhanced and make the variation appear more clearly for the user.

In the final phase of this project the VR application was to be evaluated and compared with a traditional learning situation taught by a teacher. This comparison study was very time-consuming to prepare because this phase was a crucial moment to ensure that this project would end successfully. The date for the user-test was determined, the two VR headset used for testing were booked, the VR application needed to be finished, and the user-test would only get one chance to make it all correct. With this in mind, the importance of a well-prepared test plan was crucial for this project. By writing a test plan it was possible to start with the questions asked in this master thesis and design the test based on these to make sure that all data would be collected.

The most difficult part of preparing the user-test was that this master thesis is about interaction design in VR but also aims to investigate the learning experience. Thus, it needed to be both a usability test to measure the user experience and a test of the learning experience itself. How to conduct usability testing effectively was known before, but not for an application developed in VR. Designing a test for high school students, that measured what they have learned, was much more difficult because of the lack of experience in teaching. As a consequence of this, the user-test became very complex and challenging.

## 7.3 Difficulties and limitations

During the project, there has, as in any other work, been both difficulties and limitations along the path that had to be considered. These limitations were not easy to know beforehand, because of the lack of previous knowledge of VR development. This, in turn, led to miscalculations of what was determined at the planning stage. Before entering the development phase, both Blender and Unity needed to be learned, which required many hours of video tutorials, studying other project examples, and training. All 3D models in the application, except the *crocodile clips* (downloaded from [24]), were created from scratch using Blender. This process was very time-consuming.

One of the major issues of this thesis was that there were many variables that could not be accounted for. For instance, there is no way to know if one of the two groups generally perform better than the other, or if some students had previous knowledge of the subject. There was also the issue of working with high school students as end-users, making it difficult to perform regular user-tests with the actual end-user. Working with a school also made the project very dependent on the teacher and classes schedules.

A limiting condition that had to be taken into account was the time of implementing the application. Each iteration took two weeks to complete, and even though five iterations were enough to complete a user-test, there were still improvements that could have been made.

As mentioned before, the design of the comparative study with a user-test was a time consuming and challenging step in this thesis. There was only one chance to collect all the data needed for comparing the two groups. With the user-test itself, another limitation was the small sample size, which was too small for drawing definite conclusions.

This thesis and the application only cover a small part of a single subject, i.e. electric circuit. It is, therefore, hard to draw any major conclusions about VR in learning as a whole. However, this project makes it possible to discuss the area of learning in VR with a concrete implementation as a base, rather than from an theoretical point of view.

## 7.4 Future work

There are many subjects that could benefit from using Virtual Reality as a learning tool. The ways of interacting with the virtual world used in this project worked very well, especially for users who had either seen the application being used or used it before. Basing another learning application in another subject on the same interaction pattern would create continuity which makes it easy for students to learn from any Virtual Reality learning application.

To thoroughly compare Virtual Reality to traditional learning, future studies should look at comparing VR lectures with traditional lab material and other digital learning tools.

In higher education, e.g. university, the subjects taught tend to contain more abstract concepts. Since there is at least an indication that VR can increase the understanding of such abstract concepts, more studies should also be done on higher levels of education.

This thesis does not discuss the use of Augmented Reality (AR) as a learning tool. AR has some advantages over VR especially when it comes to social aspects since the user is not isolated from the rest of the class, and perhaps more importantly, the teacher. On the other hand, AR is not as immersive as VR and could loose some of the benefits.

# CHAPTER 8

## Conclusion

This thesis set out to research the use of Virtual Reality in a learning situation. Regarding the main research question of this thesis, if VR could have a positive effect on students understanding and engagement when learning natural sciences, a decisively answer about students understanding could not be given by the result. In addition to the main research question, the following questions were asked:

- How does this learning technique differ from traditional learning where books and lectures are the primary sources of fact and information?
- Are there any differences in students' learning curve, increase of learning over time?
- How does this technology affect students' engagement when it comes to taking on and resolving new assignments?
- How can a virtual environment be created that is pedagogically correct and helpful as a learning tool when learning about the natural sciences.

Starting with the first question, there are several aspects that can be highlighted from this thesis. The power of dynamical visualization is one of the greatest difference between learning in VR compared to traditional learning. Firstly, with VR it is possible to create animations that enhance the user experience when it comes to visualizing abstract principles. Secondly, the experience of being physically involved in a situation in a natural way using your hands to grab, lift and place virtual objects, is something different. Designing for VR has the potential of combining natural learning with abstract visualization.

To be able to present information at the right time and in the right place is an important cognitive perspective in interaction design and is closely related to learning. Due to specific processes in cognition, the possibility of presenting information dynamically in VR is another great difference compared to traditional learning.

In the process of learning it is of great importance that the learner receives continuous feedback on what is happening. Compared to traditional learning it is possible in VR to add different types of feedback for an action that produces an immediate reaction for the user.

The user-test performed in this project was not able to decisively prove any positive differences in acquired knowledge for the students who used VR. However, there is at least an indication of the power VR could have as a learning tool. VR might never fully replace the more traditional ways of teaching and learning, but it has the potential of being a complement to traditional learning.

When it comes to students engagement, the results were very positive. Based on the small group who participated in the user test, a strong majority enjoyed the VR learning situation. They were all very concentrated, serious, and showed eagerness to solve the two assignments. The students were also able to, in the short time that they had, learn how to interact with the application and solve their assignments.

Regarding how to create a pedagogically correct learning tool for natural sciences, this is a pretty broad question. In this thesis, the theory around variation was used and worked very well in combination with VR. Thanks to the advantage of immediate feedback, the variation could appear in several forms for the user, e.g. sound and visualization.

When creating and designing a virtual environment that is about learning an area in the natural sciences, it is essential for the developer to understand the context, *object* of learning, and who the end-users are. In the case of a learning application, the complexity of developing for two different end-users must be taken into account. Since it is a tool for learning it must be usable by both teachers and students. In this thesis, the approach of a user-centered design process was applied through the whole project to make sure that it would be designed as a learning tool.

After completing this project, the potential of VR as a learning tool is still believed in. Electric circuits are only a small part of a whole subject matter, and there are many possibilities of enhancing the learning situation in other subjects as well. By visualizing abstract principles, having instant feedback, and giving the user the right information at the right time, VR can be used as a tool to enhance the learning experience and engage students in the learning process.

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# APPENDIX A

## Questionnaire

1. Which school do you teach at?
2. Which field do you teach in?
   - Chemistry
   - Physics
   - Biology
   - Engineering
3. Which parts in your field do you have experience of students having difficulty, or is more difficult than other parts, to understand/remember? Please describe this part.
4. Why do you think students experience this part to be more difficult and hard to grasp when it comes to learning it?
5. Do you use any tools for visualization in education today? If yes, which tools?
   - Powerpoint
   - Smartboard
   - Projector
   - Computer program
   - Tablet or Smartphone
6. What is your opinion of introducing more technology in school? Do you think it would increase students engagement and ease education when it comes to learning?

# APPENDIX B

## Interview

**Q**

What aspects are there that we can explore, in the field of electronics, that are especially difficult for the students to understand, because it is to abstract? What is difficult to visualize for the students?

**A**

Many things, everything from capacitors, [and] the resistor which is also difficult in its own way. You can explain resistance in many different way, different wire thickness, different wire lengths, but when you just look at a resistor it isn't as obvious for them. So there are a few different things that could be good. Diodes as well, why does the current only flow one way through them, and view that as a lamp, either one. So that's something that could be good to show them in some way.

**Q**

Have you had any laboratory work in connecting circuits with batteries, lamps?

**A**

Yes, general electricity teaching is common, with parallel connections and series connections etc, connecting resistors. Circuit breakers of course, making different light turn off and on. Show differences between series and parallel connections. So we did that a fair amount, and the students enjoy it a lot. It makes it more concrete, connect that, the light is on. You can also talk about why light bulbs glow, with friction and resistance.

**Q**

So what's your view on series and parallel connections? Is it difficult for the students to understand that if they connect in parallel something happens with

the resistance and if they connect in series something else happens?

**A**

I think that with regards to that they can feel that current is a bit more logical, half of the electrons go this way and the other half goes the other way. Voltage and maybe resistance is a bit more difficult to understand the differences and how it changes depending on how the connect [the circuit].

**Q**

Was there something with the laboratory material that you used, what was it especially that the students liked with it, and what would you like to see added to it?

**A**

What the digital offers is that the students get feedback directly if their ideas a right or wrong. When it comes to light bulbs, it either on or off, or perhaps glows a little less, then with [digital] they get the feedback instantly. That's one of the reasons why i think that digital and VR could help them, quick feedback on their ideas on, for instance voltage, is it correct or not, and that they can go further [in their understanding], because when they are doing laboratory assignments, you [the teacher] can only be with one group at a time. You can't go and help everybody at the same time. Sometimes it isn't needed, sometimes it is. The more abstract it gets the more use they have of us going around and helping them.

**Q**

We sent out a questionnaire to different teachers, with questions on what's difficult when teaching electronics and one teacher replied that the laboratory material was a limitation, and that sometime the quality is bad and that there wasn't enough material for all students.

**A**

Yes, it is always a bit of a sport with electronics and it is possible that the students are doing everything correctly and by accident there is a 3.5 light bulb among the 1.5 volt light bulbs and it look exactly the same. Or that light bulbs break or wires break. It's material that, even if it usually works, once in awhile . . . It wears, it's consumables. And it's annoying when students reasoned right and did right, and the result isn't right. Especially at the beginning of a subject area when they're not as confident in their knowledge, and it might take longer before they question the material and rather question what they've done. Then this particular material, it's not expensive things, so I don't see an

issue with buying the right amount and that it last pretty long, and it's really not expensive.

**Q**

Can you remember any situation when you had one of these labs or you taught electronics when you had to go to the blackboard to draw something especially difficult, you actually have to, you can't just say it you have to draw it.

**A**

Basically everything. An image is so much clearer. And with diagrams and such, if the students have to hold everything you say in their heads, maybe later in the course, connect a parallel circuit or a series circuit, and they know what that means. To draw it is really important, to be able to point and show. Or you put it on the projector.

**Q**

We focus a lot on the visual. We have considered the direction of the current and direction of electrons etc. These things are really easy for us to show. Would you consider that valuable?

**A**

Absolutely. That they have pictures and keep that with them and go back to them, is really important.

**Q**

That it sticks in their memory in a better way?

**A**

Absolutely. Sometimes you can train students in the fact that two circuit diagrams that look completely different when they look at them, are actually exactly the same diagram, just that you drew it differently. That is also something you must train a little with them. That light bulb has a direct connection with the battery even if it doesn't look like it in the diagram.

**Q**

They are use to the classic way of drawing it.

**A**

Yes. It is the clearest way of doing it, but it doesn't have to look the same.

**Q**

You teach the students one thing, you teach them how a circuit works, or what resistance is, or this is how voltage works etc. But there is some sort of insight that you want the students to reach, [or] some capability you want them to develop that they will carry the rest of their life. What is that overall goal with the teaching of electronics?

**A**

It is of course what's in the curriculum that they should know the most common components and how to use them, [and] know about circuits. In my opinion there are two more things, electrical safety at home, that they have a grasp on that, which is also in the curriculum. Then of course we have one more goal in my opinion, which is to create an interest in engineering, physics so that the chose to study what you do [engineering], because that's what society needs, to take it one step further, to increase interest, and the more practical things you can do, the more they can see and visualize, which I assume is what you are doing, it becomes more exciting, it becomes more fun, and hopefully it becomes easier. If it becomes easier, it becomes more fun and that's when you learn. It is all connected.

**Q**

Vi have thought much about the engagement, and if you can boost it with VR.

**A**

Yes I think so.

# APPENDIX C

## Test plan

### C.1 Purpose

The purpose of this test is to conduct a comparative study with the developed Virtual Reality application and traditional education. The study aims to answer the main question of this project; *could the use of VR in education have a positive effect on high school students' understanding and engagement when it comes to learning the basics in the field of natural science?* The test also aims to evaluate the VR application itself.

### C.2 Selection of participants

The test will be conducted on high school students at Lerbäckskolan in Lund. These students are part of the selection of end-users that the VR application is intended for.

### C.3 Structure of the test

In order to conduct a comparative study, the test will be divided into two phases. The first phase will consist of two groups of students. One group will have a teacher educating them in the traditional way of learning i.e. speaking and drawing on a whiteboard. The second group will be testing the VR application. From here on they will now be mentioned in this test as group 1 and group 2. The first group consists of 13 students and the second group 15 students. The lecture, held by the teacher for group 1, will contain the same information that can be learned from the application. The idea is that group 2 will gain this knowledge using the application instead.

In the second phase of the test, the two groups will be tested on their knowledge, with exactly the same questions, to collect the data needed for comparing

them. In table C.1 and table C.2 the structure of the test for the two groups can be seen.

Table C.1: Test structure for group 1

| **Step** | **Description** | **Material** | **Time** |
|---|---|---|---|
| Lecture | The lecturer will hold a lecture based on a list of features in the VR application. | | 60 min |
| Final test | The students will be answering a test based on the information from class. | Test formular | 10-15 min |

Table C.2: Test structure for group 2

| **Step** | **Description** | **Material** | **Time** |
|---|---|---|---|
| Introduction | The student will get a basic introduction of the buttons on the controllers. | - | 1 min |
| Test VR | The student will try to solve assignments in the VR application. | VR equipment | 10 min |
| Post-test questionnaire | The student will answer a few simple questions about the VR experience. | Questionnaire | 5 min |
| Final test | The student will answer a test based on the information from VR application. | Test formular | 10-15 min |

## C.4 Question formulations

This test aims to answer questions about how the students learn depending on which group they belong to in the test. Thus, the design of this test will be based on these questions, which are listed below.

1.1 Is there any differences in students' learning curve, increase of learning over time when using VR?

1.2 Does VR increase the students understanding of the relationship between current, resistance and voltage?

1.3 Does VR increase the students understanding of the relationship between current, voltage and power?

1.4 Does VR increase the students understanding of the direction of the current and electrons in a circuit?

1.5 Does the use of VR increase students engagement?

Aside from the questions of learning, the test also aims to answer a couple of questions regarding the interaction with the VR application itself.

2.1 Does the student understand what their assignment is?

2.2 Does the student understand how to complete the assignment?

2.3 Does the student realize when the specified assignment is completed?

2.4 Is a student able to connect electric circuits in Virtual Reality?

2.5 Is a student able to understand when the circuit is connected and when it is not?

2.6 Is it easy for the students to understand the interaction with the virtual environment, e.g. grabbing, lifting and using virtual objects?

2.7 Does the students enjoy using VR as a learning tool?

## C.5 Data collection

The data needed to answer all the questions mentioned above and how it is measured can be seen in the table C.3.

Table C.3: Data collection

| | **Objective/quantitative** | **Objective/qualitative** | **Subjective/quantitative** | **Subjective/qualitative** |
|---|---|---|---|---|
| 1.1 | Final test | | | |
| 1.2 | Final test | | | |
| 1.3 | Final test | | | |
| 1.4 | Final test | | | |
| 1.5 | | | Post test questionnaire | Post test questionnaire |
| 2.1 | Time to complete | Observation | Post test questionnaire | Post test questionnaire |
| 2.2 | Time to complete | Observation | Post test questionnaire | Post test questionnaire |
| 2.3 | Time to complete | Observation | Post test questionnaire | Post test questionnaire |
| 2.4 | Time to complete | Observation | | |
| 2.5 | | Observation | | |
| 2.6 | | Observation | | |
| 2.7 | | Observation | Post test questionnaire | Post test questionnaire |

## C.6 Lectures and test assignments

The first phase of the test for group 1 will be a lecture taught by the teacher. The contents of the lecture will be theoretical rather then practical. The lecture for group 2, on the other hand, will be purely practical, i.e. using only the VR application.

### C.6.1 The lecture

The teacher will be preparing the lecture based on the following features that the application supports:

- The standard components in an electrical circuit.
- The relationship between resistance, current, voltage, and power.
- When is a circuit connected.
- Which direction the current flows.
- Which direction the electrons flows.
- Series circuits vs parallel circuits.
- Resistance in series vs parallel circuits.
- How a switch (circuit breaker) works in a circuit.
- Circuit diagrams and the symbols.

### C.6.2 The VR application

To gather the required data for answering the formulated questions, the test for group 2 will consist of a couple of assignments that the students aim to solve when they interact with the VR application. The assignments is listed below in table C.4.

Table C.4: Test assignments for the VR application

| Assignment | Subassignment | Completed when.. | Max time |
|---|---|---|---|
| 1. Place the components | 1.1 Open toolbox with left trigger.<br>1.2 With your right controller grab the battery and place it on the corresponding image on the table.<br>1.3 Same as 1.2 but instead the resistor.<br>1.4 Same as 1.2 but instead grab the light bulb and place it in the socket located at the table. | All the marks are checked on the blackboard for assignment 1. | 3 min |
| 2. Connect circuit | 2.1 With either your right or left controller, grab and hold a clamp and connect it to a component.<br>2.2 Repeat step 2.1 until all components are connected with clamps.<br>2.3 Pull down the pin located on the switch in order to close the circuit. | The circuit is connected when the light bulb lights up and electricity starts animating. | 3 min |
| 3. Assign correct values to the component | 3.1 With your right controller touch a component so that it highlights.<br>3.2 With the component highlighted, press the right trigger to open the component UI.<br>3.3 Pull the slider to assign it the value that corresponds to the assignment written on the blackboard. | All the components have the correct value when the text that displays the current on the computer screen becomes green. | 1 min |
| 4. Add parallel resistor | 4.1 Open toolbox with left trigger.<br>4.2 With your right controller grab the resistor and place it on the corresponding image on the table. | All the marks are checked on the blackboard for assignment 2. | 1 min |
| 5. Connect circuit (parallel) | 5.1 Repeat step 2.1-2.3. | The circuit is connected when the light bulb lights up and electricity starts animating. | 1 min |
| 6. Assign correct values to resistors | 6.1 Repeat 3.1-3.3. | All the components has the correct value when the text on the computer screen becomes green. | 1 min |

## C.7 Test environment and equipment

The test will take place on Lerbäckskolan in Lund. The following equipment will be required to complete the test:

- Two computer that runs VR
- Two VR headset
- Four controllers
- Four sensors
- Two laptops for observation protocol
- Two laptops for post-test questionnaire

## C.8 Roles in the test

The test will require two persons to be able to collect all the data mentioned in table C.3. Both test leaders are responsible for introducing the test person to the VR application and mention which buttons are used. If the test subject has difficulties solving assignments and starts to reach the maximum time, instructions can be given. The test leaders will also observe and keep a record of the test person and how she interacts with the application.

## C.9 Result

The result of this test will be evaluated and discussed in the report of this project.

# APPENDIX D

## Final Test

## D.1 Introduction

In this test you will be asked to answer a couple of quick question about what you have learned about electronics. You do not have to worry if you do not know all the answers. Try instead to think, remember and give answers based on what you can come up with. The result from this test will not have any effect on your grades.

### D.1.1 Question 1

In which unit is voltage, resistance, and current measured?

### D.1.2 Question 2

In order to more easily remember and use the different terms in electronics every term has its own symbol. Draw a line between every letter and the corresponding term.

| | |
|---|---|
| R | Voltage |
| U | Current |
| I | Resistance |

### D.1.3 Question 3

Voltage, resistance and current have a special relationship to each other that is described by a formula. Which of the three formulas below is the correct description of this relationship. Mark only one of the alternatives.

1. I = U * R
2. R = I * U

3. U = R * I

### D.1.4 Question 4

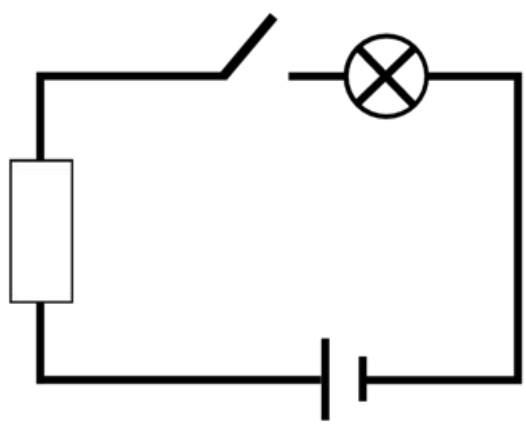
Think of an electronic circuit that consists of one battery, one light bulb, and one resistor. The circuit is connected and the light bulb is shining. What would happen with the light bulb if the resistance in the circuit was increased? Why does this happen?

### D.1.5 Question 5

Think of a similar situation as in question 4. A electric circuit consisting of one battery, one light bulb, one resistor and were the light bulb is shining. What would happen with the light bulb if the voltage was increased instead? Why does this happen?

### D.1.6 Question 6

Mark the direction of which the current and electrons are flowing in the circuit below.



### D.1.7 Question 7

Another property that one might find interesting in electric circuits is the electric power. In which unit is electric power measured?

### D.1.8 Question 8

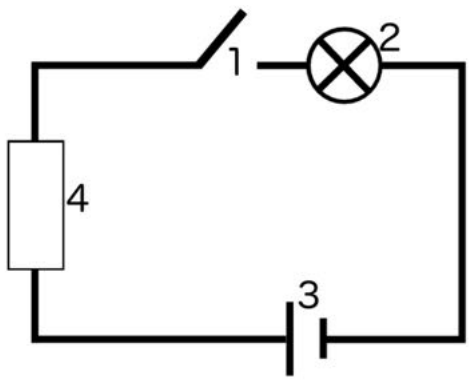
When the electric power in a electric circuit is calculated there exist a special relationship between voltage and current that is described by a formula. Which

of the listed formulas below is the correct description of the formula? Mark only one of the alternatives.

- P = U * I
- U = I * P
- I = P * I

### D.1.9 Question 9

To be able to understand how an electric circuit is connected a circuit diagram is often used. The picture below shows a circuit diagram that consist of a few components.




Which component corresponds to the correct number below?

1.

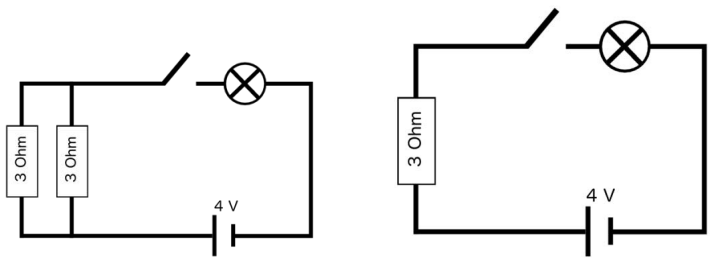
2.

3.

4.

### D.1.10 Question 10

Which of the circuits below has the highest total resistance? Mark your answer.




### D.1.11 Question 11

On a scale from 0 to 10, how interesting would you say electronics, and electric circuit is? Mark on the scale below.