UNIVERSITETET I AGDER

Experiential Learning of Chemistry Concepts Using Virtual Reality Technology

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ABSTRACT

Chemistry is a wide subject with many theoretical concepts. These theoretical concepts may be hard to grasp without experimental work. In a school class there are often students who are visual, auditory and kinesthetic learners who need appropriate tools for triggering engagement and active learning. This research discusses how adding student activities and experiments using a Virtual Reality (VR) based solution, can contribute to an enhanced learning experience for students during chemistry class. In order to produce a usable interactive VR based solution, this work followed the Human Centered Design process, which is an iterative design process when creating multiple prototypes and user tests. Students interact within a VR environment in where they perform chemical experiments and reflect on the learning activities. Participants for the user tests were comprised of junior high-school students (13 – 16 years of age) and teachers. The feedback and results from the user tests were considered for a final version of the VR high-fidelity prototype that is based on HTC Vive. The next tests investigated if junior high-school students were active and engaged when performing, observing and reflecting over chemical experiments in a virtual environment. The user tests were conducted in a controlled environment at the University of Agder. After the students had tested the VR prototype, they discussed with a science teacher about their experiences and observations in the VR system. The results showed that a VR experience in a chemistry class could be a valuable asset in combination with lectures and assignments. A VR experience can support experiential learning and increase the students' engagement and motivation by using VARK's Learning Styles, Problem-Based and Student Centered Learning approach. Consequently, the students created concrete experience by manipulating objects and performing chemical experiments in a virtual reality environment. They also reflected over the observations and explained the experienced chemical reactions. Furthermore, the students expressed that they were highly motivated to learn more about chemistry with the use of VR. Results from the tests found a high degree of the wow-factor. Thus, the students were amazed over the VR experience and the possibilities. Consequently, the students were distracted and sometimes did not hear or read important information about the various substances. Future work is suggested when VR technology is more common. Hence, the wow-factor could be decreased. There are indications that using VR in learning chemistry could be the start of a paradigm shift.

Keywords

Virtual reality; human-centered design; chemical experiments; experiential learning

PREFACE

During the 2,5 years where we have been studying for our Master degree as part-time students, and then full-time students, we have learned valuable insight to technology and pedagogy that are vital in the 21st century and for the future.

The University of Agder, Grimstad (UiA), bought a Virtual Reality (VR) device in 2016, and we saw the potential of using a relative new technology for our Master Thesis. Furthermore, we found that few people had created learning experiences for a VR system both at home and abroad. Therefore we would like to thank UiA for the access of the VR system, Christian Auby for technical assistance and Tor-Erik Klausen who bought the same type of VR system that could be used for testing at home.

We would like to give a special thank you to our supervisor Ghislain Maurice Norbert Isabwe, who gave us important advice and valuable feedback throughout the entire Master Thesis work. Not to mention our second supervisor Derek Woodgate who gave us great feedback anytime of the day/night from the USA.

In addition, we would also like to thank Rune Andersen for the help on the pedagogy aspect and contacts for participants to the usability tests, Kine Wangerud, Leader at Vitensenteret Arendal, where we tested the VR system and who also helped us in acquiring participants, Grimstad, Fjære and Holviga Ungdomsskole for providing us with science teachers and students for usability tests, Tore Vehus who contributed with a science teacher and discussions with students, Dag Boman who gave us valuable feedback on our VRBS and tasks and for using an entire day to discuss the experience with students.

Moreover, we would like to thank all the teachers we had during the Master Program and Morgan Konnestad who enabled us to be part-time students when we had jobs, full-time students and studies abroad.

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LIST OF ABBREVIATIONS

APPS   Applications

AR   Augmented Reality

ATV   All Terrain Vehicle

C   Celsius

CLP   Classification, Labelling and Packaging of Substances and Mixtures

CO   Carbon Monoxide

EXE   Executable File Format

HCD   Human-Centered Design

HMD   Head Mounted Display

I.Q.   Intelligence Quotient

PBL   Problem-Based Learning

PS4   Playstation 4

SCL   Student-Centered Learning

UiA   University of Agder

VAK   Visual, Aural, Kinestethic

VARK   Visual, Aural, Read/Write, Kinestethic

VR   Virtual Reality

VRBS   Virtual Reality Based Solution

ZPD   Zone of Proximal Development

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1   INTRODUCTION

The periodic system and chemical bondings are introduced to students when they start junior high-school. In a chemistry class, some students find the curriculum for chemical bonding difficult to comprehend/grasp and struggle with achieving learning, since the course is quite theoretical (See Appendix F). Students who have visual and kinesthetic learning styles may find science course more difficult, in contrast to students who have a read/write learning style [1], which will be addressed in Chapter 2. Hence, lack of motivation regarding learning chemistry and working on the course can occur. Mark R. Lepper and Thomas W. Malone discusses that people who are intrinsically motivated perform tasks of the enjoyment, and not because they are obligated to [2]. This research discusses how adding student activities and experiments using a VR based solution (VRBS) can contribute to an enhanced learning experience for the students during class and group work. Moreover, it will be investigated if activities with the VR system will support the students learning experience.

Utilization of VR in science education is already in use at California State University, Harvard, MIT, Stanford and Berkley [3]. They are using a fully interactive lab simulator called "Labster". In 2014, a research was done with 91 students from the Technical University of Denmark, to investigate if Labster had an impact on the students learning outcome. The results were positive, and showed that there was an increase in the learning outcome [4]. Labster and the use of VR in education will be addressed further in Chapter 2.

From Kolb's experiential learning cycle, knowledge can be achieved through experience [5]. Hence, we want to create a VR experience that students can possibly learn from. Experiential, Active and Problem-based learning (see Chapter 2) with VR can support the students to work more efficiently in the science course, due to the fact that they can draw conclusion between science and the real world. Furthermore, students can achieve the flow zone, Zone of Proximal Development (ZPD) and using fun elements in order to be engaged and motivated in their chemical VR experience (see Chapter 2 for more information).

This research will explore if a VR based learning system can enhance students concrete experience, observation, reflection, engagement and motivation in regards to chemistry, by using Kolb's Experiential Learning Cycle, different Learning Styles, Active Learning, Problem-Based Learning (PBL) , flow zone, ZPD and fun elements.

1.1   Problem Statement

In junior high-school chemistry classes, around 30% of the students struggle with chemical bonding (See Appendix F). According to the junior high-school teachers, the reason is that chemistry is quite abstract and consists of a vast amount of theoretical curriculum. These learning resources support students who have a read/write learning style [1]. The PISA (Programme for International Student Assessment) report for 2015 found that there has not been much progress in students' accomplishments in science course in primary schools in Norway since 2006. In addition, the report reveals that science is a subject with the most challenges in regards to learning and effort [6].

Few experiments in junior high-schools are executed in regards to chemical bonding and chemical reactions. The students can use a molecule building set for placing molecules together. The building set support students who have a kinesthetic learning style [1]. However, the parts for the bonding in the building set can be easily broken.

Conducting certain experiments in the classroom can be dangerous. The substances must be stored correctly and labeled according to the CLP (Classification, Labelling and Packaging of Substances and Mixtures) regulations [7] [8]. According to Kjemisk Institutt at the University of Oslo, the junior high-school students are not allowed to do experiments with substances that are corrosive, poisonous, explosive and allergenic [9]. Notwithstanding the fact that performing chemical experiments support experiential learning, where the students can combine substances, experience the reaction, reflect over the results and learn from them.

Would it be possible to create an asset where the students can do experiments in a virtual reality? The virtual environment can allow the students to explore, combine substances, experience and reflect upon the chemical reactions. Furthermore, in a virtual environment the students can do experiments with dangerous substances without the risk of getting hurt. Could a VR tool support the students in enhancing their learning experience and make them more engaged and active in learning chemistry?

1.1.1 Hypothesis and Research Questions

Based on the problem statement, this research will investigate the following:

RQ1: How to design a VR based solution that enables students to create concrete experience in learning chemistry?

RQ2: How can the students be supported in observing and reflecting upon chemical reaction through the use of VR?

RQ3: What is the effect/impact of active experimentation with VR on abstract conceptualization of chemistry concepts?

From the research questions, the hypothesis was defined as:

Hypothesis

Virtual Reality supports experiential learning and increase students engagement and active learning through a combination of practical experiments, observations and reflections.

1.2 Scope

A VRBS will be designed and developed by using the human-centered design process. The VRBS will allow the students to explore a scene in a forest. In the forest they will meet a professor who asks the students to help him with various experiments. From the Professor's book, the students can find a list of all the experiments. The book will also display hints if the students are using too much time on an experiment. The students can combine objects, which will trigger chemical reactions. After completing an experiment, the professor will ask the students "Why did this happen". Furthermore, the students will have to answer the professor out loud. Hence, supporting the reflecting upon the reaction.

1.2.1 Expected Outcomes

This research will examine if supporting the students in various learning styles with a VR based solution will make the students more active and engaged in regards to chemistry. Moreover, a VRBS will be designed and developed with the use of: Kolb's experiential learning cycle; PBL; and SCL approach. Hence, allowing the students to do experiments that are not possible to

perform during lectures, due to the danger aspects. Lastly, this study will investigate if the VRBS is an asset the students would appreciate to have as an additional learning tool for lectures and assignments in a chemistry class.

1.2.2   Limitations

Children from the ages 13 – 16 will be asked to participate in usability tests for this research. The parents' approval is required before the children can participate in regards to video recordings and audio recordings. In addition, there are many other limitations to consider when working with young children. Depending on the VR hardware, the prices vary from $5 - $799. Furthermore, the VR hardware requires a platform to run the VR software (smartphone, game console or computer). In other words, the VR equipment is too expensive for an average user, and schools are not likely to adopt the VR technology yet (see Appendix F). Another reason for not implementing a VR technology is that some users experienced motion sickness during the use of VR systems. As well as, the user cannot move entirely free when wearing specific VR headsets (Oculus and HTC Vive) since a cable is connected from the headset to the computer. The user might trip over the cable on the floor, or unintentionally pull the cable out of the computer.

1.3   Thesis Outline

Following the introduction, Chapter 2 Virtual Reality in Education – State of the Art explains the pedagogical theories used in the VRBS, the history of VR, the VR device that have been used for this research, VR in education as well as benefits and drawbacks with VR in education. Chapter 3 Design and Research Process explains the Human-Centered Design Process, which was used as the research method. Chapter 4 Use Case explains in detail how the study was planned, requirements were established, solutions were designed, and how usability tests were conducted. Chapter 5 Findings and Results explains the findings and analysis from the user tests. Chapter 6 Conclusion reflects over the findings and suggests future work.

2 VIRTUAL REALITY IN EDUCATION – STATE OF THE ART

Pedagogical approaches can be used in a VR environment with the focus on Student-Centered Learning (SCL), Active Learning, Experiential Learning and Problem-Based Learning (PBL), which contain elements that support different learning styles. VR solutions have been used in several educational concepts. This chapter addresses the pedagogical approaches and VR technologies used in the design of the VRBS.

2.1 Pedagogical foundations

This section discusses the pedagogical theories comprising of SCL, Active Learning, Experiential Learning and Problem-Based Learning. The main intention is to present pedagogical foundations underpinning the design of a VR Based Solution.

2.1.1 Pedagogy in the Digital Age

Pedagogy comes from the greek word παιδαγωγία (paidagōgia), meaning 'The leader of children' [10]. Pedagogy in the 21st century is about how teachers teach their students to add new knowledge and organize their existing one. Furthermore, to create a learning experience for the students and establish understanding [11]. Hence, the teaching methods are moving from instructivistic to constructivistic. The instructivistic teaching method according to Jonassen [12] is that teachers try to map a structure of external reality onto the students, instead of letting the students construct their own knowledge from experience, also known as constructivistic teaching method. Piaget addressed the constructivist theory of knowledge by saying that learners had to construct their concepts by the use of active and personal experimentation and observation [13] Vygotsky was the forefather of social constructivism, which is when people collaborate in order to form knowledge. Hence, solving real problems in an authentic context [11]. Vygotsky, thought that social interactions were necessary for learning, and that knowledge was co-constructed between two or more people.

In order to create knowledge for the diversity of students it is necessary to address different learning styles and the multiple intelligences. Some students learn by hands-on learning and others by visual learning. VARK is a sensory modality learning style that was created by Fleming and Mills [1] in 1992, from the work of Stirling's [14] visual, aural and kinesthetic perceptual modalities. In VARK, the V stands for *Visual*, which indicate that students prefer to receive information with graphical symbols and illustrations. The A stands for *Aural*, and describe students who prefer to receive information aurally. Hence, aural students favor

lectures and discussions. The R stands for *Read/Write*, indicating that students have a preference for receiving information as printed words. Thus, they prefer to read. The K stands for *Kinesthetic*, which describes students that prefer hands-on projects.

Howard Gardner a professor of cognition and education at Harvard graduate school of education created the theory of multiple intelligences in 1983 [15]. Gardner wrote about eight different intelligences that could measure a human being's Intelligence Quotient (I.Q.) better than the I.Q tests that were available in 1983. Gardner's eight different intelligences are: Spatial (images, graphics and spatial understanding), Bodily-Kinesthetic (body, hands and a sense of touch), Musical (music and sound), Linguistic (reading, writing and speech), Logical-Mathematical (logic, systems and reasoning), Interpersonal (work with other people or in groups), Intrapersonal (self-study and work alone) and Naturalistic (experiment in the natural world). From Gardner's multiple intelligences, different learning skills or teaching strategies can be developed [16] that fit better with the 21st century skills. Learning skills that also correspond well to the VR experience e.g. kinesthetic hands-on approaches, visual (spatial) and musical styles like audio. Considering that some learners find it easier to learn by doing rather than reading, while other learners achieve a better understanding by looking at pictures and objects.
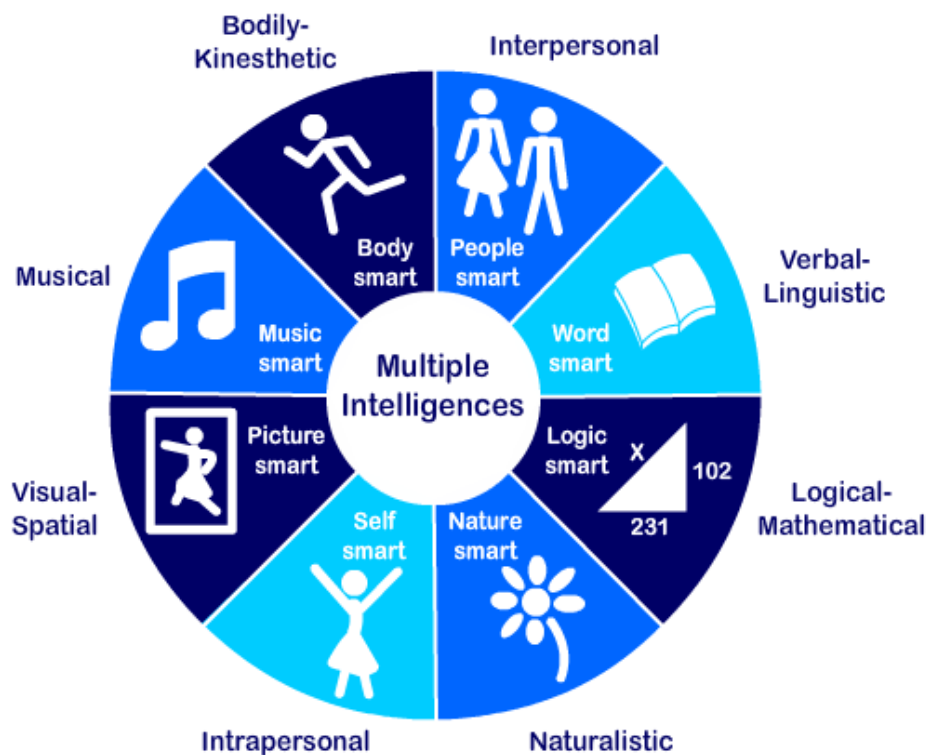
Figure 2.1: Multiple intelligences. Adapted from Gardner [15]

As seen in Figure 2.1, there are eight different intelligences adapted from Gardner. The first one that illustrates a person running is called *Body Smart*, meaning that they do well with kinesthetic learning e.g. hands-on experiences. To the right is the *People Smart,* which are persons who have a more interpersonal behavior, e.g. like to work in groups and communicates well with other people. The third one illustrating a book is called *Word Smart*, where a person has a more linguistic learning approach, meaning that you are very good at reading and writing. The next one is *Logic Smart* also called *Logical-Mathematical* intelligence, which means that people do well with mathematical and logical tasks and reasoning. Then there is the flower illustration called *Nature Smart*, meaning that you have a more naturalistic intelligence. Consequently, that you like to do experiments in the real world. The *Self-smart* illustrating a person, means that you are more of an intrapersonal individual. Which means that you like to work alone and do self-studies. Then there is an illustration of a picture frame with a person called *Picture Smart*, meaning that you have a better understanding of visual and spatial spaces, images and graphics. Thereby, your learning style can be called *Visual-Spatial*. The last one is the *Music Smart*, implying that you have more of a musical learning preference, hence you understand music and sound quite well.

VARK and Gardner's eight intelligences have been considered when the VR system was developed. The goal was to create a VR environment that supported some of VARK's different learning styles. Where VARK's learning styles could be supported by Gardner's intelligences, in order for the students to have the best learning experience. In Chapter 4, it will be addressed whether the VR system succeeded with the use of VARK's different learning styles as a source for different learning preferences.

John B. Biggs [17] argues that a good pedagogical design needs a consistency between curriculum, learning environment, teaching method and assessment procedures. In the 21st Century where learning can occur anywhere at any time with anyone, it is more important than ever that there is consistency throughout the learning process. Biggs adopted the constructivist approach where learners create their own knowledge, in order to achieve the learning consistency. One of the main factors Biggs addressed is that students have to be taught how to learn [18].

"The illiterate of the 21st Century will not be those who cannot read or write, but those who cannot learn, unlearn and relearn." Alvin Toffler [19].

In the 21st Century there are different aspects to how people learn, since the access to technology is both cheap and easy to use. Therefore, 21st Century skills and an understanding of pedagogy in a digital age are necessary. Technology is the key driver for moving from instructivism to constructivism [11]. Where the teacher together with students create understanding and knowledge, instead of telling the students what to do. Hence, using communication and collaboration from the 21st Century skills. Trilling et. al. [20] presented useful 21st Century skills, some of which will be addressed in this work. That includes communication and collaboration skills, critical thinking and problem solving and creativity and innovation skills. In the 21st Century it is necessary for people to be able to communicate across different cities and countries in order to perform their work tasks. Many jobs expect their employees to work together with their offices that are in different countries without the expense of traveling. Using technologies like Google docs and Skype, collaboration with different people, age, gender and nationality can be achieved.

Critical thinking and problem solving are other vital 21st Century skills that the future workforce have to accomplish. By using critical thinking skills people can manage projects, plan and conduct research, solve problems using appropriate digital tools and resources. With the use of innovation and creativity, students use existing knowledge to create new products and ideas, as well as construct new knowledge and develop innovative products. Furthermore, the students can use simulations and models to explore intricate issues and systems [21]. In addition, it is vital that students learn how to learn with appropriate tools. Hence, the students need study strategies and good study habits [22]. Moreover, it is necessary for students to be able to access the correct sources to obtain more knowledge. Therefore, connectivism is also a part of the learning approaches that are essential in the 21st Century, whereas obtaining new knowledge is more important than the knowledge people already possess [23]. Siemens [23] states that connectivism is based on the ability to see the difference between important and unimportant information, since new information in the 21st Century is received continually. When students enter the job market, what they have learned at school could be obsolete, and new knowledge has to be formed. In order to create appropriate study strategies, tools, habits and connections for the students the teachers have to address different learning styles e.g. VARK that can be supported by Gardner's multiple intelligences.

2.1.2   Student-Centered Learning

Student-Centered Learning (SCL) is a concept based on some work from Dewey, Rogers and Piaget [24]. Key features of SCL include: *student's responsibility, deep learning and understanding,*

active instead of *passive learning, interdependence between teacher and student.* SCL is a constructivist approach to learning rather than instructivist. Furthermore, SCL emphasizes active learning whereby the student is involved in his/her own learning and is responsible for achieving knowledge. SCL supports the students to be active participants in their own learning and develop 21st century skills, such as problem-solving, critical thinking and reflective thinking [25].

Vygotsky developed the Zone of Proximal Development (ZPD) [26]. The ZPD represents the amount of learning possible by a student who receives appropriate instructional advice [27].

Figure 2.2: The Zone of Proximal Development. Adapted from Vygotsky's theory [26]

The first circle (blue) illustrates that the student is not able to do any tasks without assistance. The second circle illustrates that the student is capable of achieving tasks with the help of e.g. a teacher and this is called the ZPD. The last circle (dark blue) illustrates that the student is able to accomplish tasks without any advice from e.g. another student or teacher. The Zone of Proximal Development, scaffolding [28] and active learning are theories that are based upon constructivism and SCL.

The ZPD fits well with Csikszentmihalyi, *Flow model* [29], (see picture below), where the flow zone is the state you are in when there is best correlation between skills and challenges. When the skills ascend, the challenges also increase, keeping people motivated to continue their tasks. The anxiety area is where the learner does not have enough skills to proceed with the task and often resigns. The boredom area is where the learner feels the task is too easy to perform, since the learners' skills proceeds the tasks difficulty level.
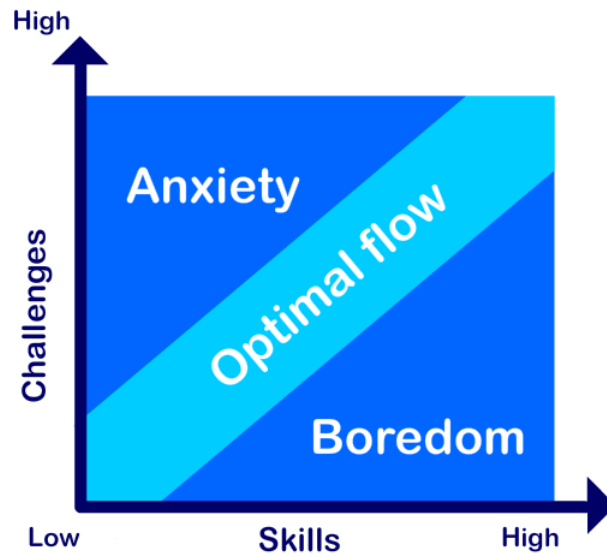
Figure 2.3: The Flow Zone. Adapted from Mihaly Csikszentmihalyi [29]

The Flow zone and the ZPD can be connected, due to the fact that the learners develop their skills and thus the need of the teacher's advice decreases. The process that allows a novice to resolve a problem, complete a task or reach a goal with assistant from an "expert" is called scaffolding [28]. Jerome Bruner, the founder of scaffolding, shared Vygotsky's beliefs that novices should receive help from experts to be able to reach the ZPD. Basawapatna, Repenning, Koh and Nickerson [30] conducted a research where middle school children were faced with game design challenges. The aim of the research was to keep the students in Flow. The teachers provided scaffolding for the students when necessary to help them through ZPD and back to Flow. The authors called this space the Zone of Proximal Flow. The results showed that the Zone of Proximal Flow is effective, and keeps the students engaged in their tasks. The ZPD and the Flow model are considered in designing the VR technology based learning system. This is to ensure that the given tasks/experiments are neither too difficult nor too easy for the students to perform. Thereby, the students can get into the flow zone during the VR experience. Simultaneously, the students receive appropriate amount of advice and hints during the experience. Thus, creating a ZPD and Flow zone for the students to keep them engaged and motivated. In addition to considering the level of difficulty with regards to the ZPD and the Flow model, it is important to enhance students´ motivation. Malone and Lepper [2] defined intrinsic intrinsic motivation in learning by four types: challenge, curiosity, fantasy and control. The first type called *challenge* must provide accurate goals to perform, provide performance feedback and have an uncertain outcome. The *curiosity* aspect can be sensory by the use of sound and interactive changes. The *fantasy* aspect involves skills being learned and the fantasy depending

on each other. The last one is the control aspect where the learner needs a sense of control, contingency, power and choices. It is suggested that intrinsic motivation will likely occur when the students are having fun while learning, hence the students are engaged in the learning for their own benefit.

In the VR system there is the influence of a flow zone and ZPD with intrinsic motivation types such as target goals to perform called experiments, sound that provides hints, interactive objects that can be manipulated, VR skills that can be learned (using the VR controllers e.g. teleporting) and chemical understanding including choices to make (which task to do first and how). Thereby, keeping the students motivated and engaged in the VR experience.

2.1.3 Active Learning

Active learning happens when students, instead of passively observing, are involved in the learning activities like hands-on projects, discussions, role play, evaluations, group studies etc. Thus, creating higher-order thinking skills such as synthesis, evaluation and analysis [31]. Bonwell and Eison [32] describe an active learner who is involved in their studies, as someone who is doing something and also thinking about what he/she is exactly doing. Students who are actively using tools in their studies, create a rich understanding of the tools and of the world where the tools are used [33]. Brown [33] described learning as a continuous life-long process which is a result of acting in situations. Thus, students have to be active in order to create knowledge. Moreover, from active learning there is a link to constructivist learning through the work of John Dewey [34]. Dewey wrote about teachers' instructions where not only theoretical but also practical [34]. The teachers could not only learn in theory, they also needed practical experience and vice versa. Using the VR learning system, students get active through hands-on activities in the virtual environment. Additionally, they will have discussions with a teacher and fellow students after the VR experience. Thus, creating active learning supported by a VR system.
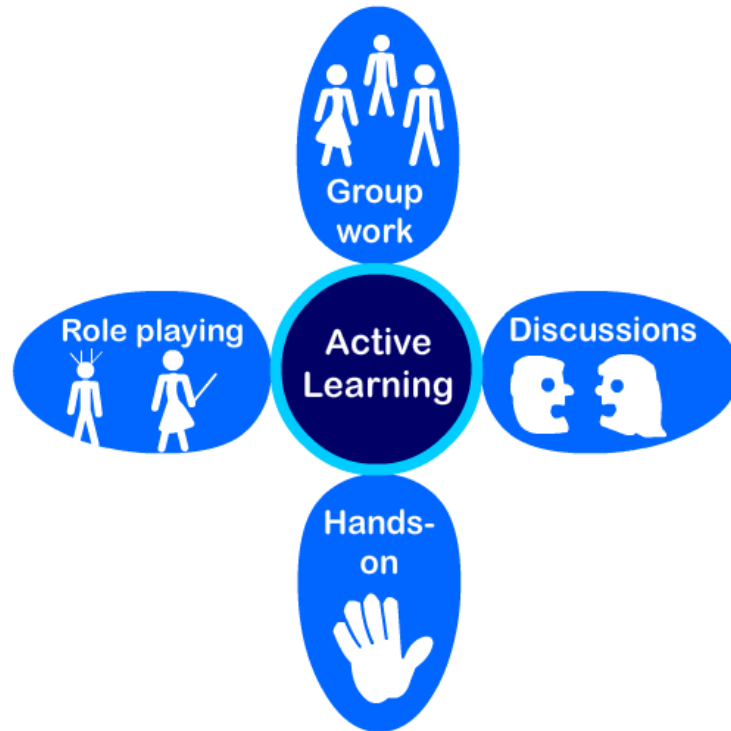
Figure 2.4: Active learning activities. Created by Marie Ristesund

When students are involved in their learning activities, it is important that they are engaged during the learning experience. With student engagement it is believed that students who are curious, focused and inspired will likely have a better learning outcome, than students who are bored, unfocused and disengaged [35]. With *physical engagement* learning and interest can be encouraged, like e.g. the students could go up to the board and write the answers to the given questions [35]. In the VR experiential system, the students will move around and use hand controllers to perform tasks. Thereby, physical engagement can occur. Pedagogues can use different forms of procedures to encourage positive emotions in students, which will support the learning process, reduce bad behavior and prevent students from dropping out [35]. Thus, *emotional engagement* can develop. During the VR experience there is one task that creates an explosion with sound, that can trigger an emotional reaction. Other tasks can also create emotional engagement which will be addressed in Chapter 4. With the use of *behavioral engagement* teachers can create classroom routines, use specific signals, or assign students roles that encourage behavior that promotes learning. E.g. the teachers could clap their hands to regain the students focus, and ask students to lead the student activities [35]. In the VR experiential system, the students have to use the controllers in a certain way to be able to teleport and pick up objects. Consequently, behavioral engagement can occur when the students use the controllers and move around in the VR environment, hence keeping the students active.

2.1.4   Experiential Learning and Problem Based Learning

According to David Kolb [5], *experiential learning* occurs when experience is at the center of the learning process. He states that *"Knowledge is continuously derived from and tested out in the experiences of the learner."* [5]. Hence, knowledge occurs through experience. Kolb used experiential learning to combine experience, cognition, perception and behavior. It is noted that John Dewey, Kurt Lewin and Jean Piaget are the founders of the experiential learning method [5]. Later on, Kolb proposed the experiential learning cycle comprising of four main phases as shown in Figure 2.6: *Concrete Experience, Reflective Observation, Abstract Conceptualization and Active Experimentation* [5]*.*

Figure 2.5: The Experiential Learning Cycle. Adapted from Kolb [5]

- *Active Experimentation*: students plan and try out what they have learned from their experience.
- *Concrete Experience*: students gain experience from a task.
- *Reflective Observation*: students reflect upon their experience.
- *Abstract conceptualization*: students draw a conclusion upon their reflection.

For the VR experiential system, the active experimentation has been selected as the first stage, since the goal was that the students should use what they had learned at school in order to perform the experiments in the VR system. Then the students would gain experience when executing the experiments/tasks. Afterwards they would reflect on their experience with a

teacher and other students. As a result, the students would hopefully learn from the VR experience.

Effective learning can be achieved when the learner completes the whole cycle. Kolb's ideas of experiential learning are not fixed elements of thoughts, instead they are formed and reformed through experience. Learning is a process where concepts are derived from and constantly altered by experience. Kolb states that *"No two thoughts are ever the same, since experience always intervenes"* [5]. Using the VRBS, all the four stages of Kolb's cycle can be achieved.

There are studies that indicate that knowledge acquired from problem solving mode, is more likely to be active and used [36]. According to Howard S. Barrows and Robyn M. Tamblyn [37] *"Problem-based learning is the learning that results from the process of working toward the understanding or resolution of a problem. The problem is encountered first in the learning process!"*. Whenever while attempting to solve a problem, learning occurs. In order to enhance the learning experience in chemistry, the students should be able to solve given problems through experiments. Some schools allow students to perform experiments, and other might not have the resources to do so. In addition, some of the substances in chemistry might be dangerous. In that case the teacher would have to perform the experiments while the students are passively observing. As a result of this being an instructivist teaching method, the students may not be able to solve any problems on their own. Eraut [38] argues that most learning happens in the workplace, rather than by following instructivist teaching methods. This indicates that learning can happen through solving the given problems. *Problem-Based-Learning* [11] allows the students to develop their creativity and independence. They can visualize how their results can be applied in the real world. In the VR experiential system, students can solve tasks by experimenting and using their creativity when manipulating objects in order to create a chemical reaction.

2.2   Virtual Reality Systems

Virtual Reality (VR) is a technology where users can access a virtual environment and experience it as if they are there physically. VR can be used for both entertainment and education [39]. The sales of VR equipment are rapidly increasing. Statista [40] found that the worldwide shipment of VR head-mounted displays was 140.000 in 2015; 1.43 million in 2016 and it is expected to be 6.31 million in 2017.

The history for VR started as early as 1838 with stereoscopes and viewers [41]. Charles Wheatstone [42] found that the brain organizes different two-dimensional images for each eye into one single object with three dimensions. The user got a sense of depth and immersion when viewing the stereoscopic images side by side through a stereoscope. In 1939 the View-Master was released, which is based on Wheatstones´ stereoscope. The View-Master shown in Figure 2.6 was used for "virtual tours" and as a toy for children. The same principles from the stereoscope are used today for Google Cardboard.
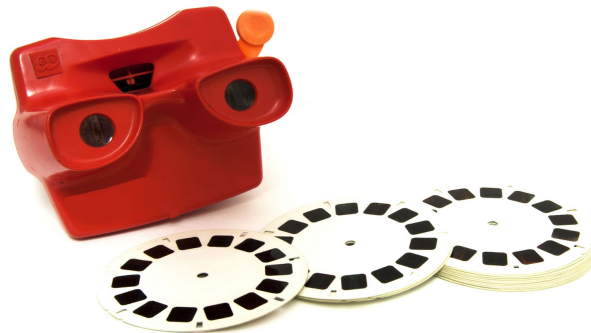
Figure 2.6 A View-Master with slides

Several Virtual Reality devices were released in 2016 by renowned brands like Sony, Oculus and HTC [43]. The development of Virtual Reality devices has been tried out several times, although the technology for full immersive experience has been missing. In 2016 several options for a Virtual Reality device became available for purchase.

Google developed the VR platform Google Cardboard [44]. Google Cardboard is a plain cardboard that folds into a viewer. Users can download specific applications (apps), for example Google Expeditions, and place their smartphone inside the Google Cardboard. Google also released a VR headset in 2016, called Google Daydream [45]. A smartphone that is Daydream-ready is placed inside the headset. The phones that are Daydream-ready have high-resolution displays and high-fidelity sensors for head tracking [46]. The Google Daydream is equipped with a remote control that the users can operate when navigating in the VR environment. The Samsung Gear VR [47], powered by Oculus [48], is a head-mounted device where the users place their Samsung Galaxy smart phone inside the device, and strap on the head-mount. Then, the users can browse and download more apps from the Oculus Store. The Playstation VR [49] from Sony is a head-mounted device, which the player connects to a Sony Playstation 4 (PS4) with a Playstation Eye (Camera for PS4). The player handles the Playstation Move Controllers when playing. The Oculus Rift [50] is a VR head-mounted device (HMD) that is connected to a PC. The

Rift has integrated 3D audio headphones, rotation and position tracker. The users have a sensor placed on their desk, that allows them to use the Rift when sitting or standing. HTC Vive [51] is a VR device, which is used for PC. Sensors are placed on opposite sides of the room to utilize "room scale" technology and convert the room into a virtual reality space. The user can walk around and use motion tracked handheld controllers to manipulate and interact with objects. HTC Vive will be used for this research. The main reason for choosing the HTC Vive is that it has two handheld controllers for interacting, and can be used with room scale, allowing the user to operate the HTC Vive in the entire room. HTC Vive comes with one headset, two controllers and two infrared base station lighthouses. The base stations register where the headset and controllers are within the *play area.*

Figure 2.7: HTC Vive headset, controllers and base stations [52]
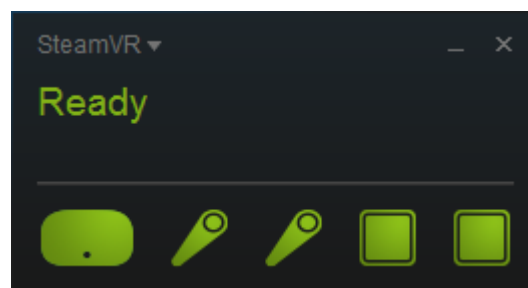
Figure 2.8: Connection Status with SteamVR

The software Steam by Valve Corporation [53] with SteamVR needs to be active when using the HTC Vive. The green icons in Figure 2.8 indicates that the controllers and the sensors are on, the Head Mounted Device (HMD) is head tracking and that everything is within the field of view for the sensors. When all the icons are green, the user can start the VR experience.

The *play area* defines where the user can move freely during play and avoid walking into walls and furniture. In order to define the play area, the user must use the Room Setup from Steam VR. From there the user has to hold down the trigger button on one of the controllers, and move

around the area, mapping the borders of the area. Once the play area is configured and saved the HTC Vive is ready to be used.
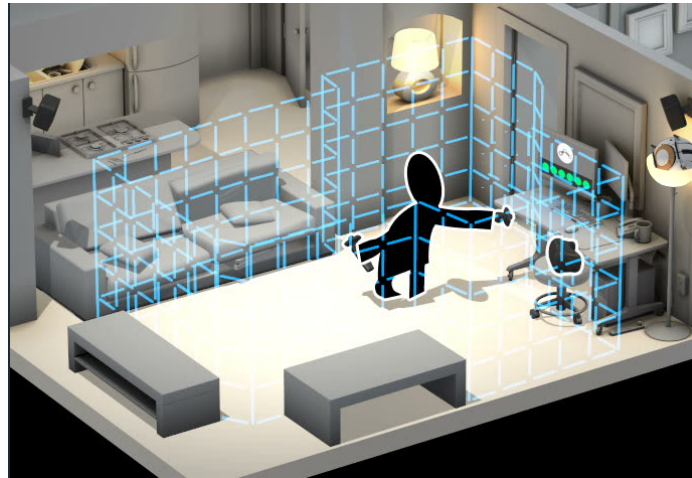
Figure 2.9: Defining the play area with the Room Setup from SteamVR

The headset is equipped with a front facing camera and 32 sensors. The front facing camera registers obstacles in front of the user. When the user is approaching a wall, a grid will be visible for the user. Hence, indicating that the user is about to collide into something in the room. The base stations register the position and rotation of the headset, ensuring accurate motion tracking. The field of view for the headset is 110°, with a 2160 x 1200 resolution and 90 Hz refresh rate [54].

Figure 2.10: The HTC Vive headset [52]

Both of the controllers have 24 tracking sensors for accurate tracking, which is registered by the lighthouses. The trigger button supports the user in interacting with elements in VR. The trigger button uses haptic technology for feedback to the user. The dual grip buttons are for specific games, but not often used. When pressing the System button the dashboard for Steam will be visible. If the user presses the System button again the dashboard will be hidden.

When pressing the menu button the menu for the current active game will be visible.

The Touchpad also uses haptic technology for feedback to the user. In VR the user can see a circle on the touchpad, which indicates the position for the user's finger. The status light has

three different lights indicating various statuses for the controllers. A green light indicates that the controllers are on; a blinking orange light indicates that the batteries are low; a white light indicates that the controllers are charging.

When the VR experience has a larger scene than the play area, the user can teleport when moving throughout the scene. How this can be done depends on how the game is developed, although usually the user presses the touchpad for teleporting.

In the VRBS the trigger button on the right controller supports the user in manipulating objects by picking up, moving, throwing and combining them with other objects. The trigger button on the left controller allows the user to look inside the professor's notebook. The notebook lists all the chemical experiments that the user can perform in the scene. The touchpad, on both controllers, allows the user to teleport in the scene.

Figure 2.11: The HTC Vive controllers and button names. Adapted from HTC Vive Image Gallery [52]

The base stations beam infrared (IR) signals to find the position and rotation for the headset and the controllers. They must be placed on opposite sides of the play area (not more than five meters apart) and above the user to ensure that the headset and the controllers are always within the field of view [55].

Figure 2.12: The HTC Vive base stations [52]

When a person is using a VR device, she/he may encounter both physical and mental experiences. A person could become *immersed* and experience the *wow-factor*. According to the Oxford Dictionary, the wow-factor can be defined as a feature that is extremely impressive [56]. Many people who try VR for the first time experience the wow-factor. In addition to experiencing the wow-factor, they can become immersed in the VR experience. Meaning that they can potentially perceive the virtual reality as a physical reality. When standing on the edge of a cliff edge, the users can feel that if they take another step they will fall. Although in the physical world they are just standing on the floor, for example in their living room. Additionally, some users can experience illness when immersed in a VR experience. This is due to the mismatch between the muscles and the inner ear. The users can see some movement, but cannot physically feel it [57]. This can lead to the user experiencing nausea or motion sickness.

2.3 Virtual Reality as a Learning Tool

VR in education is mostly used as a simulation tool, for example to experience traveling to different countries or going back in time. In example, a reporter for the BBC UK (United Kingdom) visited a class that used Google Cardboard with Google Expeditions [58]. With Google Expeditions the students are able to go on field trips that would be more or less impossible in real life. The students can go back in time to ancient Egypt, they could go whale watching under the sea or go to space and visit Mars [59]. There is a growth of companies developing educational curriculum and content with the use of VR.

zSpace [60] allows several users to collaborate when exploring the virtual environment. The users wear lightweight zSpace glasses where an external screen will display a virtual reality environment. The users will use the zSpace pen or their hands to interact with and manipulate objects, for example the human heart where the users can hold the heart with the pen, and feel the heart beats.

Alchemy VR [61] uses 360 video, which is viewed in a 360° angle, for narrative storytelling with realistic 3D models of objects. For example documentaries about the Great Barrier Reef, where the users will encounter sea animals up close.

Immersive VR Education [62] develops training and simulation for education and lectures. For example ER VR [63], a medical training simulation. In the simulation the users work as medical assistants, where they try to save a person who has been involved in a traffic accident.

Figure 2.13: Print screen from ER VR [63].

In 1996, John T. Bell and H. Scott Folger [64] investigated the development and testing of VR based educational module prototype called Vicher (**Vi**rtual **Che**mical **R**eaction Module). Their results from the preliminary testing showed that the students had a slightly increased understanding of the covered concepts. The company "Labster" [3], in Denmark, has developed a fully interactive lab simulator, which includes gamification elements, storytelling and a scoring system. Students are enabled to see the connection between science and the real world. The simulator is being used at California State University, Harvard, MIT, Stanford and Berkley to name a few. In 2014, to investigate if Labster improves the students learning outcome, a research was done with 91 students from the Technical University of Denmark. The results showed that there was a 76% increase in learning outcome when using virtual laboratories instead of traditional teaching methods [4].

Figure 2.14: Print screen from Labster. Retrieved from Labster [3].

In 2000, Don Allison and Larry Hodges [65] tested a virtual reality gorilla system on middle school children where they found that the students were captivated by the technology, and were excited about the lesson even before the class had started. With VR in science education, in addition to traditional teaching methods, the students might become more engaged and achieve a better learning experience. By using experiential learning, problem-based learning and active learning approaches with VR technology, students can be able to work more efficiently in the course, since they experience the connection between science and the real world. Considering that the students will be working in a VR environment there is no risk of getting hurt when doing experiments with hazardous elements. Furthermore, the schools will have access to unlimited elements without any additional cost in regards to purchase, transportation, storage and safety. Cleaning of equipment is not necessary, allowing the students to spend more time on the experiments. The students can do the experiments in the VR system themselves, instead of passively watching the teacher doing experiments in the real world. Hence, the students are able to achieve hands-on training. Thereby, moving away from the instructivistic teaching methods towards the constructivistic approach.

However, some students can potentially experience motion sickness when immersed in a VR experience. Measures have to be taken in order to prevent motion sickness from happening. One option is to use a computer that is powerful enough to run the VR application as well as being aware of the issue during design and development of a VR application. If motion sickness is not considered during design and development, then a powerful computer may not help with preventing nausea.

At the moment, the VR devices fit most eyeglasses, but not all of them. This could be an issue in the classroom if there are students who are not able to use the HMD because of the size

of their glasses. However, for some VR devices, for example HTC Vive, it is possible to change the foam inserts and nose pads inside the HMD, which might give more room for different eyewear.

Many VR devices are still quite expensive, ranging from $5 to $799. In addition, when purchasing a VR device there is also a need to buy hardware that can run VR applications. This could be either a smartphone or a computer. Schools may not have enough funding for purchasing the VR devices and other necessary equipment. However, it is not unlikely that the devices will become more affordable in the future. This has been the issue with several new technologies. In 1982 the Commodore 64 had a marked value of $595 [66], which converted to the year 2016 would be around $1.488 [67]. In 2016, a laptop can have a marked value of $300. Moreover, not all teachers are technically proficient, and they will need training in the use of the VR system. Thus, it might be costly and time-consuming to use the system. The system has to be set up correctly and it requires specific space to do so. Many schools may not have these resources available for a VR system. Although, the next generation (Millenials[1]) might be more experienced with the newer technologies, which can lead to the next generation of teachers to be more proficient with VR technology. Furthermore, by planning on which days to use the VR device, the teacher can move the desks in a horseshoe shape in the classroom and set up the equipment in the middle of the room.

Tilt Brush[2] by Google is a virtual reality drawing experience where the users draw in 3D space with virtual reality. The right controller is used for painting, while the left controller serves as the user's toolbox. In the toolbox the users can change the paint color and the paintbrush. The users can also choose "Teleportation" from the toolbox, and can teleport by using the right controller. Tilt Brush is a good option for experiencing VR for the first time, considering that it allows the user to become familiar with being immersed in a virtual environment, as well as getting to know and learn how to use the controllers. When testing the VRBS, the participants will try the Tilt Brush first, hence preparing them for being immersed and get to know the controllers.

Augmented Reality (AR) adds virtual elements to the users' reality. Nintendo AR [3]and Pokemon GO[4] are examples of technologies using AR. The camera on the device displays what

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[1] Millenials are people who approach earily adulthood in the early 21st century.

[2] Tilt Brush: https://www.tiltbrush.com/

[2] Tilt Brush: https://www.tiltbrush.com/

[3] Nintendo AR is a game that comes with the Nintendo 3DS system. The game uses cards that are placed on a flat surface and the user looks at them through the camera on the 3DS system. Game characters and objects will appear on the flat surface.

[4] Pokemon GO is an app on smartphones where the users can collect pokemons.

the user is pointing at as well as virtual elements. Figure 2.15 shows a print screen from a smartphone where the user is hunting for pokemons at a grocery store. Mixed Reality (MR) adds holograms to the users' reality. The technology used for MR is spatial mapping. Spatial mapping gives a detailed representation of the surfaces in the present environment [68]. Hardware using the MR technology is Microsoft HoloLens[5] [69].

Figure 2.15: Pokemon Go: The user can capture a pokemon at the grocery store.

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[5] Microsoft HoloLens is a holographic computer, which enables interacting with holograms.

3   DESIGN AND RESEARCH PROCESS

For this research the human centered-design (HCD) process was used to understand the context of use, establish requirements, design prototypes and conduct usability tests. As seen in Figure 3.1, the HCD process is an iterative process consisting of the following parts [70]: Plan the human-centered design process; Understand and specify the context of use; Specify the user requirements; Produce design solutions to meet user requirements; Evaluate the designs against the requirements; and Designed solutions meets user requirements.
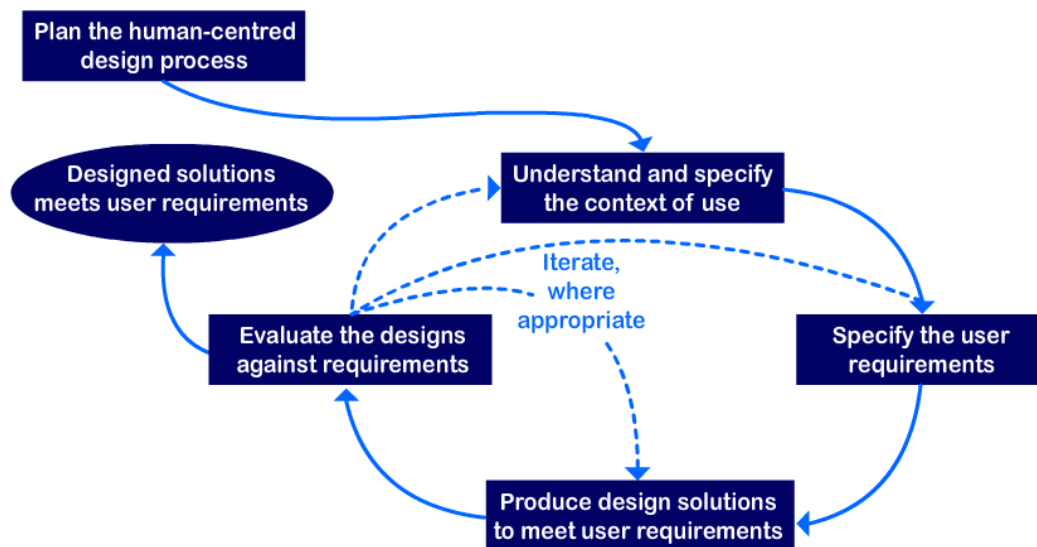
Figure 3.1: Interdependence of the HCD activities. Adapted from [70]

3.1   Plan the Human-Centered Design Process

The HCD process has to be thoughtfully planned and managed during the whole process to be successful. The process ensures that the artifact is structured and designed in regards to the users and their needs [71].

3.2   Understand and Specify the Context of Use

Relevant data needs to be collected in order to understand and specify how the artifact should be used [72]. The data supports finding the target audience (population) and their goals for using the artifact. Furthermore, the data can be collected by conducting structured or semi-structured interviews, or by handing out questionnaires. The questions can be open and closed questions. Open questions allow the participants to elaborate on their answer, however the closed questions are either multiple choices or Likert scales. Likert scales should have at least

five responses, either with numbers or indicate how much the participants agree or disagree, approve or disapprove. With Likert scales the participants can give a degree of opinion in their answers [73]. In structured interviews the interviewer usually asks closed questions, similar to questions from a questionnaire. With semi-structured interviews, the interviewer might ask both closed and open questions. For this research, a junior high-school teacher explained what the students learn in regards to chemistry and chemical bonding in 8th, 9th and 10th grade. The teacher explained that the school does not perform many experiments, instead the students use a molecule set to create and explore the molecules. Moreover, the students can explore molecules using applications (apps) on a tablet.

3.3   Specify the Requirements

When designing an artifact that is meant to support the users, it is important to know who is the target audience and what type of support should be provided. This is the foundation for the requirements and to determine how to design and develop the product. The requirements are established through data gathering and analysis [72].

James and Suzanne Robertson [74] created the Volere requirements template. The Volere requirements support testing as soon as they have been established. A requirement is testable through its fit criterion. If the fit criterion cannot be met, it means that the requirement is either not concrete or too ambiguous. Software Requirement Specification (SRS) [75] is a software system description for a system that includes specific functions. The supplier and/or the customer can write the SRS. The SRS includes information regarding functionality, external interfaces, performance, attributes and design constraints.

The Volere Requirements have been chosen for this research, since adding, editing and deleting requirements through the iterative HCD process are more efficient than they are with the SRS. Functional and non-functional requirements can be established efficiently with the use of the Volere Shell Template. The requirements are iterated further in regards to the results from the user tests.

Figure 3.2: An example of a Volere shell requirement. Adapted from [74].

Functional requirements state what the product should be able do. An example of a functional requirement for a mobile phone could be that it should allow the user to make calls and send messages [72]. *Non-functional requirements* state the constraints and the development for the product [72]. For example, a non-functional requirement for a mobile application would be that the buttons should be large enough to support touch. Several functional and non-functional requirements have been established in regards to the VRBS. The requirements describes how the system should support the students in performing chemical experiments when using the Experiential Learning Cycle, PBL and SCL approach.

3.3.1 Usability and User Experience Goals

According to Jakob Nielsen [76], usability specifies features for a system, which supports a human when interacting with, installing and maintaining the product. The standard usability goals are *Effectiveness*, *Efficiency*, *Safety*, *Utility*, *Learnability* and *Memorability*.

- *Effectiveness*: The system should allow the users to complete tasks.
- *Efficiency*: The users should be supported in completing their tasks in a productive manner.
- *Safety*: The user should not encounter any errors. If there are errors, the user should be able to recover from them.
- *Utility*: The system should provide functionality that supports the user in completing tasks.

- *Learnability*: The system should be easy for the user to learn.
- *Memorability*: It should be easy for the user to remember how to use the system.

User Experience goals are various emotions and felt experience that can be either positive or negative. Some examples of user experience goals can be satisfying, helpful, fun, boring, frustrating and annoying [72]. For the VRBS, these usability goals have been essential when designing and developing the solution. The VRBS should support the users in performing the experiments without a vast amount of steps. Consequently, since the scene is in a large forest, the user should be constrained to a specific area to avoid the user in getting lost. The users should be guided by the system with graphics and audio content to complete the experiments. Moreover, the users should be supported in learning the system quickly by adding guiding assets. Furthermore, by minimizing the number of controller functions, the users should be able to easily remember how to use the system.

3.4   Produce Design Solutions

Once the requirements are established the design process can begin. The process can be divided in two sub-categories: *Conceptual Design* and *Physical Design*. For the conceptual design, a conceptual model will be created for the product. This model describes a walkthrough of the entire system and how the users can interact with it [77]. The physical design describes the details for the product. Details like colors, images, fonts and layout [72]. Conceptual design involves designing the tasks and the interactions between the tasks with the use of analogies and metaphors [77]. With conceptual design the users will get an understanding of the product and how the interaction works. A part of the conceptual design process is creating user stories and scenarios. *Stories* are real-world experiences, thoughts and understandings from the users. These stories can be in any format, e.g. videos or photographs, and provide a solid basis to design scenarios [78]. *Scenarios* are specific stories illustrating the use cases for the design solution. There are two main types of scenarios: conceptual and concrete scenarios. The conceptual scenarios are abstract whereas the concrete scenarios are more specific [79]. The user-system interactions can be visualized with *use cases*. The use cases show a set of actions that the user has to go through to complete a goal when using the system [80].
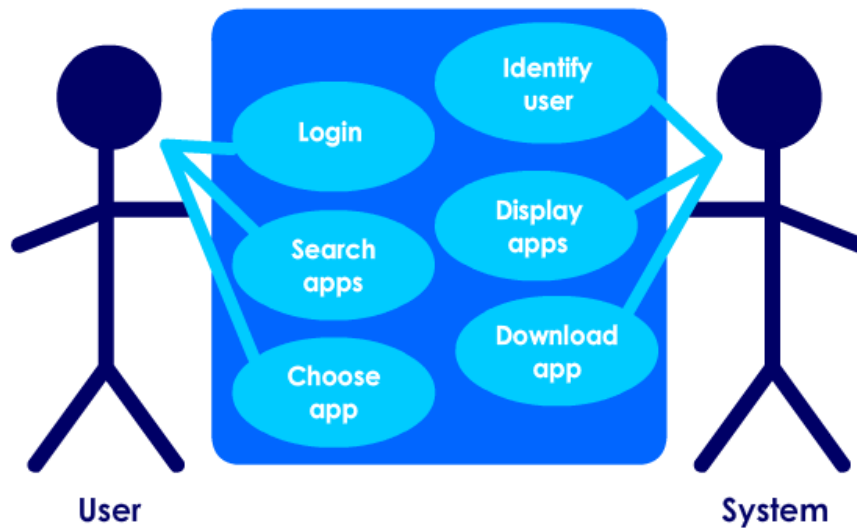
Figure 3.3: Use Case of downloading an application (app). Adapted from Sharp et. al. [72].

The details for the product, for example colors, fonts, sounds and images, are considered for the *physical design* [72]. Since the design process is iterative, it is necessary to go back and forth between the conceptual and the physical design. The usability goals and the user experience goals have to be considered in regards to the functional requirements [81]. For the VRBS the users should be engaged and active and perform experiments by using the experiential learning cycle, PBL and SCL approach. It should also support various learning styles by adding graphics, sounds, text and elements to manipulate. Scenarios and use cases were created to establish the conceptual design. Based on the conceptual design and the requirements, the physical design was created and iterated further.
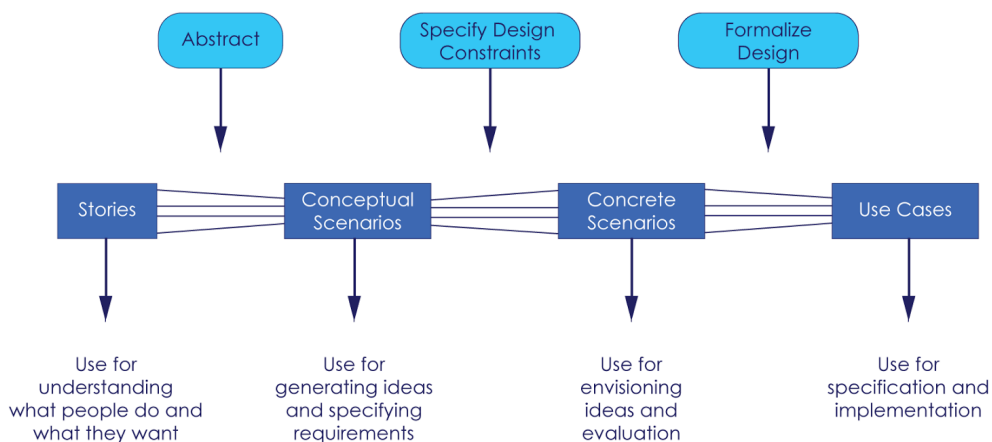
Figure 3.4: Scenarios throughout design. Adapted from [82].

3.4.1 Affordances

An affordance supports or assists the user in doing something [83]. Referring to H. Rex Hartson, four types of affordances in HCD can be defined and used. These affordances are:

- *Cognitive affordances*, which is a design feature that affords the user in knowing something.
- *Physical affordances*, which is a design feature that affords the user in doing physical tasks.
- *Sensory affordances*, which is a design feature that affords the user in sensing something.
- *Functional affordances*, which is a design feature that affords the user in accomplishing tasks [84].

In the VRBS, the objects in the scene offer cognitive affordances for the users, for example the objects can be picked up, moved and thrown. During testing of the VRBS, some users tried to drive an All Terrain Vehicle (ATV). Since the ATV offers cognitive affordances for driving, the users asked "Can I drive this?". However, the VRBS did not support driving the ATV. The system offers physical affordances in regards to the user pressing the trigger button on the right-handed HTC Vive controller to manipulate and combine objects. The trigger button on the left-handed HTC Vive controller affords the user in triggering an object. When releasing the trigger button, the object will be hidden. In addition, the user can move around in the scene by pressing the touchpad to teleport. Sensory affordances are offered since the users can look at signs and read information. In addition, sensory affordance is offered when audio clips in the VRBS are played. Functional affordances are offered in regards to the controllers supporting the user in manipulating objects, teleporting and triggering an object.

3.4.2 Prototyping

An important part of the design process is prototyping, which encourages the designers to reflect upon the created product [85]. A prototype allows the stakeholders to interact with and explore the functionalities within the product. The product should be tested to identify potential usability problems early in the design process. With a prototype the users can interact with the system and test if it matches the requirements. The quickest and cheapest type is a *Low-Fidelity prototype* (for example paper prototypes). More advanced prototypes are called *High-Fidelity prototypes*, where the user interacts with an almost finished product. For this research a low-fidelity prototype and a high-fidelity prototype were designed and developed. The low-fidelity prototype is cheap and fast to produce [86]. In addition, design flaws and issues can be

addressed early in the design process, before the development process starts. The high-fidelity prototype gives the user an immersive experience that is needed in a VR environment, which cannot be achieved in a low-fidelity prototype. When the user has attached the HMD with audio headset, he/she will mostly experience the VR environment, and the audio from the real world is hard to hear. Hence, creating a full immersive experience. A low-fidelity prototype does not necessarily resemble the final product. It can be made out of cardboard and paper instead of using a digital tool. The use of such a prototype is mainly for exploration, to try out new ideas and alternative designs in a cheap and effective manner. Examples of low-fidelity prototypes are storyboards and paper prototypes. A storyboard is a sequence of events that the user has to go through in order to achieve tasks. A paper prototype can be created to test the physical design for the product. It is made of sketches, prints and sticky notes illustrating the interface in different settings [87] [72]. A high-fidelity prototype looks like the final product and it can be built using production/digital tools. This kind of prototype is used for testing and for finding out potential issues that might arise in the final product. The low-fidelity prototype for the VRBS was created with pictures, paper figures, a cardboard box and empty soda bottles. A storyboard was made with various drawings of the VR scene. Graphics software, 3D modeling tool, developer software and a game engine have been used during design and development of the high-fidelity prototype for the VRBS.

3.5 Test and Evaluate the design

During testing and evaluation, the usability of the product is tested and analyzed to check if the designed product meets the requirements. Participants are recruited and given tasks for user testing, which will determine if the product meets the usability goals and user experience goals. The DECIDE framework provides a checklist that provides a structure for planning usability tests and evaluations [72].

D - Determine the goals
E - Explore the questions
C - Choose the evaluation methods
I - Identify the practical issues
D - Decide how to deal with ethical issues
E - Evaluate, analyze, interpret and present the data

Figure 3.5: DECIDE framework [72].

3.5.1 Determine the Goals

What are the goals for the evaluation? Goals will help to set the direction for the evaluation, and that is the first step when planning, testing and evaluating. Two types of tests were conducted in regards to the VRBS. The goal for the first test was to examine if the system supported the usability goals. The goal for the second test was to evaluate the learning experience.

3.5.2 Explore the Questions

Questions should be formulated and be answered during the testing and evaluation. These questions should be clearly defined in regards to the usability goals and user experience goals. The questions for the first usability test was to determine if the system had good learnability and would work without critical errors, as well as establishing if the users were able to complete the tasks and were pleased with the experience. When testing the learning experience, the users should be able to perform the tasks without assistance, be engaged in the VR environment as well as observing and reflecting over the chemical reactions.

3.5.3 Choose the Evaluation Methods

The evaluation methods must be chosen after setting the usability goals and questions. The evaluation type depends on the questions and the type of data to be collected. A combination of different methods can give more information on how well the product meets the requirements.

There are three settings for evaluation.

- Controlled environment involves users where the main methods are direct observation and cognitive walkthrough. These methods are good at finding usability problems. However, it might be difficult to see how the artifact would function in the intended environment.
- Natural environment involving users, that can for example be online forums or public places. This approach is good at capturing how the artifact would function in the intended environment. However, it might be expensive and challenging to achieve.
- Any settings not involving users where the methods include inspections, walkthroughs, models and analysis. These methods are cost efficient and quickly performed. Nonetheless, usability problems might be missed. [72]

 Cognitive walkthrough and the *Think-Aloud Technique* are examples of evaluation methods. According to Nielsen and Mack [88], cognitive walkthrough is when the users are replicating their problem-solving process for each progression in the human-computer dialog. The facilitators can see how the users interact with the system and how they complete their goals [88]. According to Nielsen [76], the Think-Aloud Technique gives a direct understanding of where the user encounters problems, since the method demonstrates how the user understands the system. Although, the Think-Aloud Technique has some drawbacks, since the participants cannot always say what they are thinking. *Direct observation* lets the facilitators observe what the individuals are doing, how they are performing tasks and interacting with the system. A controlled environment can be a laboratory or a controlled room where no disturbance from outside factors can occur. Roussou, Oliver and Slater [89] investigated user interaction in VR with focus on the effects of interaction and conceptual learning. The method chosen for their study was, amongst others, direct observation. Direct observation with the Think-Aloud Technique in a controlled environment was chosen as the evaluation methods when testing the VRBS. The participants explained what they were thinking and doing in the VR environment. Thereby, allowing the observation of the participants during their interaction with the system to perform chemical tasks. Thus, supporting answers to the questions for the tests. However, sometimes they forgot to speak out loud. In addition, when an audio clip was played, the participants stopped talking.

3.5.4   Identify Practical Issues

When identifying the practical issues a pilot study might be useful for identifying problems. These problems can be corrected before the actual usability test. Practical issues could include technology problems e.g. the computer, headphones or the camera not working, as well as access to participants, facilities and equipment [72]. Recruiting participants for the testing of the VRBS was a challenge since the stakeholders were busy with exams. The tests were conducted at UiA and equipment was available at the same location. Pilot sessions were conducted before the participants arrived to test the VRBS. The pilot session supported checking if the system worked accordingly. If any errors occurred the issue could be addressed before the actual tests.

3.5.5   Decide how to Deal with Ethical Issues

Ethical issues should be considered when collecting data from the participants. Their privacy must be protected. Personal data has to be confidential and it should not be possible to identify the participants from research reports and publications. Each participant has to sign a consent

form where they agree upon participating in the study and either approve or disapprove of being video recorded and/or audio recorded [72]. In regards to this study, the recruited participants for the usability tests were less than 18 years of age. An application for approval to collect data was sent to NSD[6] before any data were gathered. Consent forms for parents and teachers were prepared as well. When the approval from NSD (see Appendix A) was received, the consent forms were sent to the participant's parents (see Appendix B). The consent forms included information about the project in addition to asking for permission to video and audio record the participants. The teachers were asked to sign consent forms upon arrival to the usability tests.

3.5.6   Evaluate, Analyze, Interpret and Present the Data

The data should be evaluated and analyzed once it has been collected. The facilitators should check if the data is reliable and valid, if there are any biases and if the results can be repeated. *Quantitative data* is either in the form of numbers or it can be converted to numbers. Analyzed quantitative data can determine the size or amount of something. For example, in describing a population of science teachers, a quantitative analysis can determine that the average science teacher is between 30-40 years old. *Qualitative data* can be descriptions, quotes or images. Analyzed qualitative data can be illustrated with categories, themes and stories. For example, when describing the same population, a qualitative analysis can determine that the average science teacher is a man. Table 3.1 displays a summary of how to process the collected data from these techniques.

	Usual raw data	Example Qualitative data	Example Quantitative data	Initial processing steps
Interviews	Audio recordings. Interviewer notes. Video recordings.	Responses to open questions. Video screenshots. Respondent's opinions.	Age, job role, years of experience. Responses to closed questions.	Transcription of recordings. Expansion of notes.
Questionnaires	Written responses. Online database.	Responses to open questions. Responses in 'further comments'. Respondent's opinions.	Age, job role, years of experience. Responses to closed questions.	Clean up data. Filter into different data sets.
Observation	Observer's notes. Photographs. Audio and video. Data-logs. Think-aloud.	Records of behaviour. Description of a task as it is undertaken. Copies of informal procedures.	Demographics of participants. Time spent on a task. The number of people involved in an activity.	Expansion of notes. Transcription of recordings. Synchronization between data recordings.

Table 3.1: Data gathered and standard progress for the main data gathering techniques. Adapted from Sharp et. al. [72].

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[6] Norwegian Center for Research Data

Data from interviews are usually in written notes, audio and video recordings. Those data should be analyzed early, while it is still fresh in the interviewer's memory. It is likely that the interviewer potentially still remembers gestures from the participants during the interview session [90]. Video recorded semi-structured (or unstructured) interviews with open answers should be transcribed since the participants might give more broad answers than the closed questions in a structured interview. With the transcription, the facilitators can categorize the responses in themes and patterns. The interviews can be transcribed in a spreadsheet, for example Google Sheets[7], to provide an overview of the responses.

The collected data from questionnaires can be on paper format or from online surveys. The data should be cleaned before analyzing by removing responses where the participants have misunderstood the question. The data can be sorted by a subpopulation or by questions. For interviews and questionnaires, open questions are usually analyzed as qualitative data, and closed questions as quantitative data. A tool for analyzing the data from questionnaires is Google Forms[8]. The questionnaires can be created from Google Forms, then share the link with the participants, or the facilitator can add the written responses manually to the online questionnaire. Google Forms will automatically sort the collected data into pie charts and bar graphs.

Data collected from observations can have a wide variety. It could be observers' notes, photographs, think-aloud recordings, video and audio recordings from interviews [72]. The facilitators would have to transcribe the audio and video recordings, as well as the think-aloud records. In order to find specific patterns in the recordings, the audio and video need to be coded for specific cases, or the facilitators would have to manually go through all of the video and audio recordings to find behavior of interest. This process can be uninspiring, time-consuming and impossible [90].

For this research both qualitative and quantitative data were collected from interviews, questionnaires and observations. The interviews were video recorded anonymously and transcribed (see Appendix F) in a spreadsheet, which provided a straightforwardly overview of the users answers. The questionnaires were provided to the participants on paper. Therefore, the questionnaire and the responses were added to Google Forms, which supported evaluating and analyzing the data efficiently. The observations were video recorded and manually analyzed.

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[7] Google Sheets: https://www.google.com/sheets/about/

[8] Google Forms: https://www.google.com/forms/about/

4   CASE STUDY

A case study is a thorough research about a topic in a concrete setting. Case studies follow a process, for example the Human-Centered Design (HCD) process, for gathering, evaluating and analyzing both quantitative and qualitative data [91] [92].

According to Yin [91], the advantages with case studies are: The evaluation of the data is often done within the intended setting; variations in processes support collecting both quantitative and qualitative data; results that may not have been found with experimental research or surveys. The disadvantages with case studies are according to Yin [91]: "too often, the case study facilitators are careless, and allow unclear evidence or biased views to alter the results and conclusions; Since some facilitators may use a small number of participants it may provide very little basis for scientific generalization; Case studies are often thought of as being too comprehensive, hard to manage and produces a greatly amount of documentation".

For this research the case study research method with the HCD process was chosen when designing and developing a VRBS. A case study research method with the HCD process would support design and development of a VRBS that would assist all stakeholders. This case study will research if the junior high-school students can experience chemical concepts, specifically chemical bonding and chemical reactions, by interacting with a VR based solution. Hence, supporting experiential learning.

4.1   Requirements Elicitation for the VR Based Solution

In regards to establishing the requirements and the scenarios for the VR based solution, a meeting with a junior high-school student was scheduled. The teacher explained what the students are learning about science in the 8th, 9th and 10th grade. Consequently, with the teacher's information, it became possible to establish what the students might need for a potential experiential learning tool in their chemistry class. The teacher's science books Eureka! 8 [93], Eureka! 9 [94] and Eureka! 10 [95] were used as well. In one of the science books there was information about the dangers of carbon monoxide (CO). Additionally, there was an example of a person who had died when sleeping in a tent with a used disposable grill left inside, and that it was essential to teach students about the dangers of CO. Therefore, one of the tasks in the VRBS would be for the student to rescue a person choking from CO in a tent, whom the student has to pull out of the tent before proceeding with tasks to perform. In considering that it was a person in a tent, it was natural to have the scene in a forest. A scene most of the Norwegian kids are familiar with. Wherefore, it was decided to go for a scenario where the user is in a forest with a science professor, a tent and a disposable grill. The science professor was

chosen since this is a person with a high education, who tries to do experiments, but fails and needs help from students in order to perform the tasks. Furthermore, the professor could guide students through the experiments with voice and with hints from the professor's book. Students can use the professor's book that contains hints that can help them achieve the tasks. Moreover, the students will receive additionally information from the professor who talks to them and guides them through the experiments when necessary. The experiments should not be too easy or too hard to perform. Thereby, creating a flow zone to achieve with ZPD for the students, to keep them motivated and engaged.

The professor is a male person, for the reason that most professors in movies are projected as males. Movies such as Back to the Future[9], The Nutty Professor[10] and Jurassic Park[11] all have male characters that are professors. Hence, creating a natural setting for the scene.

The experiments are non-typical for a classroom, which were inspired by a performance called "Naturfag Rocker" [96]. On the grounds that the users are able to do chemical experiments in VR, without the risk of getting hurt, one of the experiments are "Create a huge explosion". The users will solve the experiment by throwing a gasoline can into a campfire. Then they will experience what happens when gasoline interacts with heat and oxygen. In addition, creating a fun experience with sound and graphics.

Liquid nitrogen with regular and boiling water was chosen for the other experiments, given that liquid nitrogen is also an element that is too dangerous, as well as expensive for classroom experiments. "Naturfag Rocker" also used liquid nitrogen and boiling water in some of their experiments, that results in a major reaction from the audience. This was also the reason for choosing these substances since this reaction might lead to the students creating a concrete experience. When an experiment is completed, the professor will shout out "EUREKA". The statement was chosen since this is also the same title as the junior-high school student's chemistry books. After the conversation with the junior-high-school teacher and reading through the teacher's science book the requirements could be established. The Volere Shell template was used to set the requirements [74].

Functional requirements were established to support the user in using the entire play area, display molecules and information about the substances, interact with objects, experience reactions when combining objects and receiving hints when the user is inactive.

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[9] Back To The Future. A movie from 1985 starring Christopher Lloyd as Dr. Emmet Brown.

[10] The Nutty Professor. A movie from 1996 starring Eddie Murphy as professor Sherman Klump.

[11] Jurassic Park. A movie from 1993 starring Richard Attenborough as professor Richard Hammond.

Requirement #: 1   **Requirement type**: 9   **Event/use case**: 1

Description: The product should display a forest with tasks related to learning chemistry

Rationale: To be able to enhance the learning experience for chemistry students

Originator: UX Designer

Fit Criterion: The user will have a familiar scene to do chemistry learning tasks. Since a forest is more familiar for the students than a fully equipped laboratory.

Customer satisfaction: 5   **Customer Dissatisfaction**: 3

Priority: 5

Conflicts: -

Supporting Materiale: Eureka! 10, Naturfag for ungdomstrinnet, Lærerenes Bok [95]

History: October 2nd 2016

Requirement #: 2   **Requirement type**: 9   **Event / Use case**: 2

Description: The product should allow the user to explore a scene larger than the actual play area in the physical room.

Rationale: To make the user move around the room and be fully immersed in the experience

Originator: Software Developer

Fit criterion: When exploring the scene the user will be fully immersed in the VRBS.

Customer Satisfaction: 4   **Customer Dissatisfaction**: 3

Priority: 4

Conflicts: -

Supporting Materials: Virtual Reality Society, Virtual Reality Immersion [97]

History: October 3rd 2016

Requirement #: 3   **Requirement type**: 9   **Event / Use case**: 3

Description: The product should display hints for the user when they are not making any progress.

Rationale: To be able to encourage the user in regards to given tasks and continue the VRBS.

Originator: Software Developer

Fit criterion: When the user has activated an object relevant for the experiment, a hint will be displayed after 60 seconds.

Customer Satisfaction: 5   **Customer Dissatisfaction**: 5

Priority: 5

Conflicts: -

Supporting Materials: Lev Vygotsky [26], Mind in society: The development of higher psychological processes

History: October 3rd 2016

Requirement #: 4   **Requirement type**: 9   **Event / Use case**: 2

Description: The product should display a chemical reaction when combining specific substances.

Rationale: To be able to achieve learning when experiencing the reaction between combined chemicals.

Originator: Software Developer

Fit criterion: When the user combines objects there will occur a similar reaction like the real world. This illustrates for the user how the chemicals and the chemical reactions behave in real life.

Customer Satisfaction: 5   **Customer Dissatisfaction**: 5

Priority: 5

Conflicts: -

Supporting materials: David Kolb [5], Experiential Learning

History: October 3rd 2016

Requirement #: 5   **Requirement type**: 9   **Event / Use case**: 2

Description: Teleportation should only be available in part of the scene.

Rationale: To be able to keep the user at the specific area, and prevent them to get lost in the scene.

Originator: UX Designer and Software Developer

Fit criterion: When the user is exploring the scene they should be constrained to the specific area, instead of the whole plane. This is to make the user feel safe since they will not be able to get lost in the scene.

Customer Satisfaction: 4   **Customer Dissatisfaction**: 3

Priority: 4

Conflicts: -

Supporting Materials: Jakob Nielsen [76], Usability Engineering

History: October 4th 2016

Requirement #: 7   **Requirement Type**: 9   **Event / Use case**: 2

Description: The experiments should be typical "non classroom" experiments.

Rationale: To be able to perform and learn from dangerous experiments, without the risk of getting hurt.

Originator: UX Designer and Software Developer

Fit criterion: The experiments should be the types that are not possible to perform in the classroom. Either because of the danger hazard and/or the lack of resources.

Customer Satisfaction: 5   **Customer Dissatisfaction**: 5

Priority: 5

Conflicts: -

Supporting materials: Universitetet i Oslo – Kjemisk Institutt, Regler og ansvar på naturfagrommet [9]

History: November 14th 2016

Requirement #: 8   **Requirement Type**: 9   **Event / Use case**: 1

Description: Students should see the molecules and atoms for the chemicals.

Rationale: To be able to physically see how the molecules and atoms are built up.

Originator: UX Designer and Software Developer

Fit criterion: When the user interacts with objects in the system, the molecule or atoms for the substance will be visible and attached to the selected object. The user can pick up the object and have a closer look at the molecule or atom.

Customer Satisfaction: 5   **Customer Dissatisfaction**: 5

Priority: 5

Conflicts: -

Supporting materials: David Kolb [5], Experiential Learning

History: November 15th 2016

Requirement #: 9   **Requirement Type**: 9   **Event / Use case**: 1

Description: The system should display information about the specific substances.

Rationale: To be able to read about the substances.

Originator: UX Designer and Software Developer

Fit criterion: When the user interacts with objects in the system a sign with information about the substance will be visible. The user can read the sign for more information about the substance and subtle hints on how to finish an experiment.

Customer Satisfaction: 5   **Customer Dissatisfaction**: 5

Priority: 5

Conflicts: -

Supporting materials: Neil Flemning [1], Not Another Inventory, Rather a Catalyst for Reflection and Lev Vygotsky [26], Mind in society: The development of higher psychological processes

History: November 15th 2016

Requirement #: 10   **Requirement Type**: 9   **Event / Use case**: 1

Description: The product should play audio clips with information about substances.

Rationale: To be able to hear information about the substances.

Originator: UX Designer and Software Developer

Fit criterion: When the user interacts with objects in the system an audio clip with information about the substance will be played. The user must listen to the audio clip to receive information about the substance.

Customer Satisfaction: 5   **Customer Dissatisfaction**: 5

Priority: 5

Conflicts: -

Supporting materials: Neil Flemning [1], Not Another Inventory, Rather a Catalyst for Reflection and Lev Vygotsky [26], Mind in society: The development of higher psychological processes

History: November 15th 2016

Non-functional requirements were established to state how and when to use the artifact with the VR hardware, as well as how to prevent nausea during the immersive experience.

Requirement #: 6   **Requirement Type**: 10   **Event / Use case**: 1

Description: The tool is a supplement to lectures and assignments.

Rationale: To be able to support the students in observing and reflecting upon chemical reactions.

Originator: Software Developer and UX Designer

Fit criterion: During or after the VRBS, the students and the teacher will discuss the experiments and the chemical reactions they experienced.

Customer Satisfaction: 5   **Customer Dissatisfaction**: 5

Priority: 5

Conflicts: -

Supporting materials: David Kolb [5], Experiential Learning

History: November 14th 2016

Requirement #: 11   **Requirement Type**: 10   **Event / Use case**: All

Description: The artifact should be used with a HTC Vive where the play area is defined as room scale. The room size must be at least 2 m x 1.5 m [12].

Rationale: To be able to use the product in room scale and interact with objects with the controllers.

Originator: UX Designer and Software Developer

Fit criterion: With a room scaled play area and controllers, the user is more likely to be immersed in the VR environment.

Customer Satisfaction: 5   **Customer Dissatisfaction:** 4

Priority: 5

Conflicts: -

Supporting materials: HTC Vive User Guide [55]

History: November 16th 2016

4.2   Producing the VR Design Solution

When the requirements were established, working on the design solution was started by creating scenarios, a storyboard, use cases and prototypes. *Conceptual scenarios* can be used for creating design ideas and establishing requirements [82]. Any person, regardless of computer skills, can try the VRBS with some input from the facilitators or teachers. The students can explore the scene, walk around and touch objects with the controller in order to receive

information about substances and chemicals. Furthermore, they can select an object and place it with another object in order to experience and learn from the chemical reactions, when the objects are combined. In regards to *Kolb's Experiential Learning Cycle* the students should be supported in creating a concrete experience when combining the objects. After the chemical reaction has occurred, the student will be asked by the professor why the reaction happened. Then, he/she has to respond out loud what he/she thinks could be the reason for the chemical reaction. This supports the students in reflecting upon their experience. Moreover, the activity allows students to reflect upon the experience in a way that matches the "Reflective Observation" phase from Kolb's Experiential Learning Cycle [5]. W. Vasbinder and W. Koeheler [98] did a research to find out if experiential learning would enhance student engagement. They investigated the outcomes of semester-long experiential learning projects in five business courses in college. The students worked with startup companies to create and present strategic business plans. Hence, determine factors that promote or hinder student engagement in experiential learning. Results from that research showed high levels of student engagement. The students were also pleased to be able to use theoretical lessons from their undergraduate business education in their projects.

Concrete scenarios can be used in regards to prototyping, generating ideas and evaluation [82]. The concrete scenario for this research was as follows:

"During chemistry class Peter has received a task from his teacher to explain what carbon monoxide can do to humans and how the molecule is built up. Peter wants to engage with the VRBS in order to do the task. He needs to experience the chemical substances in a virtual reality environment, to get a better image of how all the chemicals are connected in a real world. Peter puts on the VR gear and starts exploring the scene. A professor tells him to help him out of the tent since there is too much carbon monoxide inside. Peter drags the professor out of the tent. Suddenly a sound clip plays. The professor thanks Peter for rescuing him from CO poisoning and is grateful for giving him access to oxygen. In addition, information about oxygen and the O_2 molecule are visible. Peter touches a disposable grill, which is inside the tent, with the controllers and receives detailed information about CO (Carbon Monoxide) substance, molecule structure and that it is dangerous to have it inside the tent. Peter now has enough information about CO to do the task he received from his teacher. He removes the VR gear and starts working on the task that his teacher gave to him. "

4.2.1 Use Cases for the VR solution

The use cases for the VRBS provided an overview of the interactions between the system and the user.

Use Case 1

1 The system displays a forest scene with objects to explore; a tent, a fireplace, a lake, and a sign that explains how to pick up objects, how to find the notebook and how to teleport.

2 The user looks at the sign.

3 The user moves around in the forest and explores the scene.

4 The system plays an audio clip where a professor asks the user to pull him out of the tent.

5 The user pulls the professor out of the tent

6 The system plays an audio clip where the professor tells the user that he now has access to oxygen.

7 The system displays an oxygen molecule.

    7.1   The user looks at the molecule

8 The system displays a sign with information about oxygen.

    8.1   The user reads the sign

2. The system plays an audio where the professor asks the user to perform experiments from book.

3 The user finds the book.

    3.1   The system plays an audio clip where the professor confirms that the user has found the book.

4. The user reads through the experiments.

5. The user moves in the VR scene by teleporting to the lake

6. The user fills the bucket with water

7. The system displays the water molecule and text information about the water molecule (H_2O).

Use Case 2

1 The system displays a forest scene with objects to explore; a tent, a fireplace, a lake and a sign that explains for the user how to pick up objects, how to find the notebook and how to teleport.

2 The user looks at the sign.

3 The system plays an audio clip where the professor asks the user to pull him out of the tent.

4 The user explores the scene and looks at the objects.

5   The user teleports to the tent.

6   The user holds the professor.

7   The user pulls the professor out of the tent.

8   The system plays an audio clip where the professor tells the user that he now has access to oxygen.

9   The system displays an oxygen molecule.

10   The system displays a sign with information about oxygen.

     10.1   The user reads the sign

11   The system plays an audio where the professor asks the user to perform experiments from the book.

12   The user finds the book.

     12.1   The system plays an audio clip where the professor confirms that the user has found the book.

     12.2   The user reads through the experiments.

13   The user teleports to the gasoline can.

14   The user touches the gasoline can.

     14.1   The system displays the C_8H_{18} molecule.

     14.2   The system displays a sign with information about gasoline.

         14.2.1   The user reads the sign

         14.2.2   The system plays an audio clip where the professor tells the user about gasoline.

15.   The user selects the gasoline can.

16.   The user teleports to the campfire.

17.   The user throws the gasoline can onto the campfire.

18.   The system displays an explosion.

     18.1   The system plays an audio clip of an explosion.

     18.2   The system plays an audio clip where the professor says that the experiment was a success.

Use Case 3

1   The system displays a forest scene with objects to explore; a tent, a fireplace, a lake and a sign that explains for the user how to pick up objects, how to find the notebook and how to teleport.

2   The user looks at the sign.

3   The system plays an audio clip where the professor asks the user to pull him out of the tent.

4   The user teleports to the tent.

5   The user selects the professor.

6   The user pulls the professor out of the tent.

7   The system plays an audio clip where the professor tells the user that he now has access to oxygen.

8   The system displays an oxygen molecule.

9   The system displays a sign with information about oxygen.

   9.1   The user reads the sign

10   The system plays an audio where the professor asks the user to perform experiments from the book.

11   The user finds the book.

   11.1   The system plays an audio clip where the professor confirms that the user has found the book.

   11.2   The user reads through the experiments from the professor's book.

12   The user teleports to the gasoline can.

13   The user touches the gasoline can.

   13.1   The system displays the C_8H_{18} molecule.

   13.2   The system displays a sign with information about fuel.

      13.2.1   The user reads the sign

   13.3   The system plays an audio clip where the professor tells the user about gasoline.

14   The user does not know what to do for 60 seconds and does not manipulate any objects.

15   The system activates a hint for the experiment.

16   The system plays an audio clip where the professor tells the user that a hint is available in the book.

17   The user opens the book.

   17.1   The user looks at the hint.

18   The user selects the gasoline can.

19   The user teleports to the campfire.

20   The user throws the gasoline into the campfire.

21   The system displays an explosion.

   21.1   The system plays an audio clip of an explosion.

   21.2   The system plays an audio clip where the professor says that the experiment was a success.
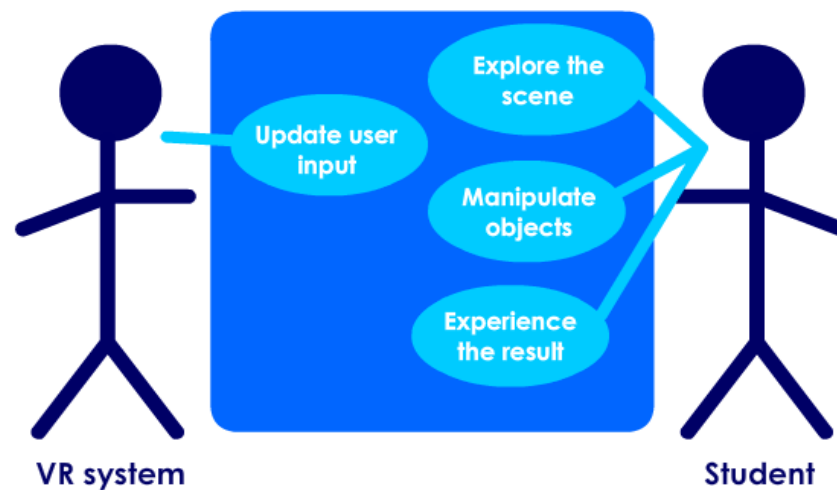
Figure 4.1 Use case diagram for the VRBS. Adapted from Sharp et. al. [72].

Essential use case

User intention	System responsibility
Explore and find information about Carbon Monoxide	Display the scene and available objects
Help the professor out of the tent	Play audio clip with instructions
Touch the disposable grill with the controller	Display Carbon Monoxide information and molecule. Play audio clip about Carbon Monoxide
Read the experiments from the book	Display the book
Touch the gasoline can with the controller	Display text information about C_8H_{18}, and the molecule. Play audio clip with information about C_8H_{18}.
Pick up the gasoline can	Display hint in the book if the user has not finished the experiment during the next 60 seconds.
Throw the gasoline can on the campfire	Display an explosion and play explosion sound. Play "Why did this happen" audio clip.
Answer the professor, and explain why the explosion happened.	Future Work: Play sound to inform user if he/she is right or wrong.

Table 4.1 Essential Use Case for the VR system

4.2.2   VR Design Solutions

After establishing requirements, scenarios and use cases the storyboard was created to visualize the VRBS. A storyboard is an efficient and effective technique to showcase the ideas and thoughts of the product [99]. For the VRBS, a storyboard consisting of drawings was created.
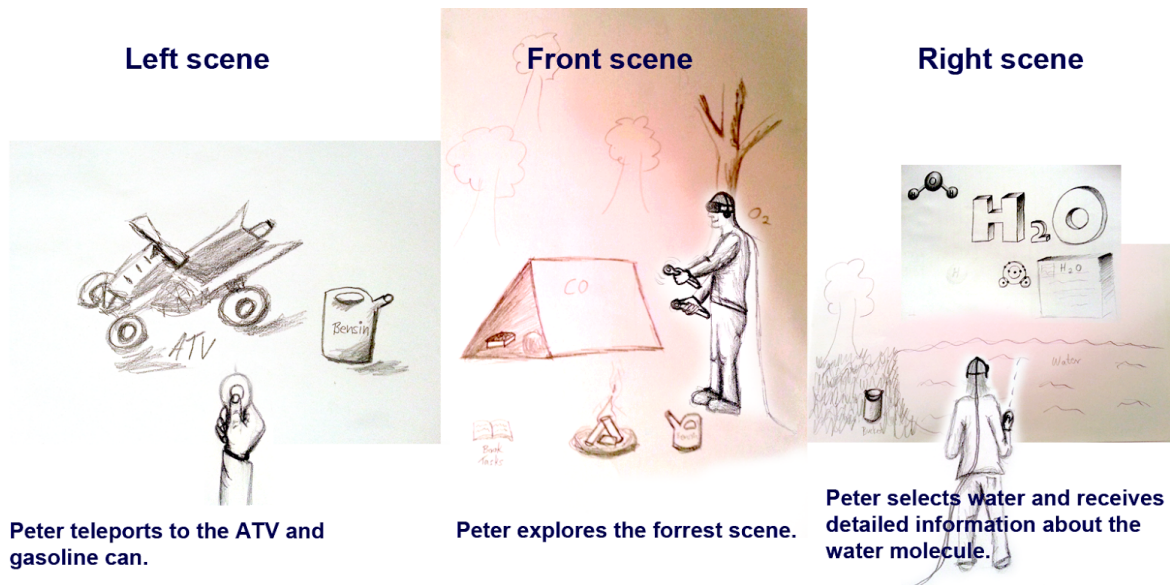
Figure 4.2 The storyboard where the user is exploring the forest scene

The storyboard is a collage of sketches showcasing how a user is exploring the forest scene and performing tasks. The storyboard helped visualize the forest scene with all the necessary objects for task executions. As seen in Figure 4.2, the middle sketch called *Front scene*, displays a VR user exploring the scene. The scene consists of a tent with a man and disposable grill inside, a campfire and trees behind the user showcasing that it is a forest scene. The scene to the right called *Right scene* displays a user selecting the water and receiving the water molecule symbol and text information. Next to the water is a bucket that the user can fill with water. The left sketch called *Left scene*, displays the user who has teleported to the All Terrain Vehicle (ATV) and gasoline can.

Based on the ideas and user feedback on the storyboards, a low-fidelity prototype was created with prints, paper, boxes, empty soda bottles and a book.

Figure 4.3 The low-fidelity prototype for the VRBS

Figure 4.4 To the left, a paper tent with a stick figure and a paper disposable grill. To the right, a campfire and information about carbon monoxide.

Figure 4.5 Low-fidelity usability testing
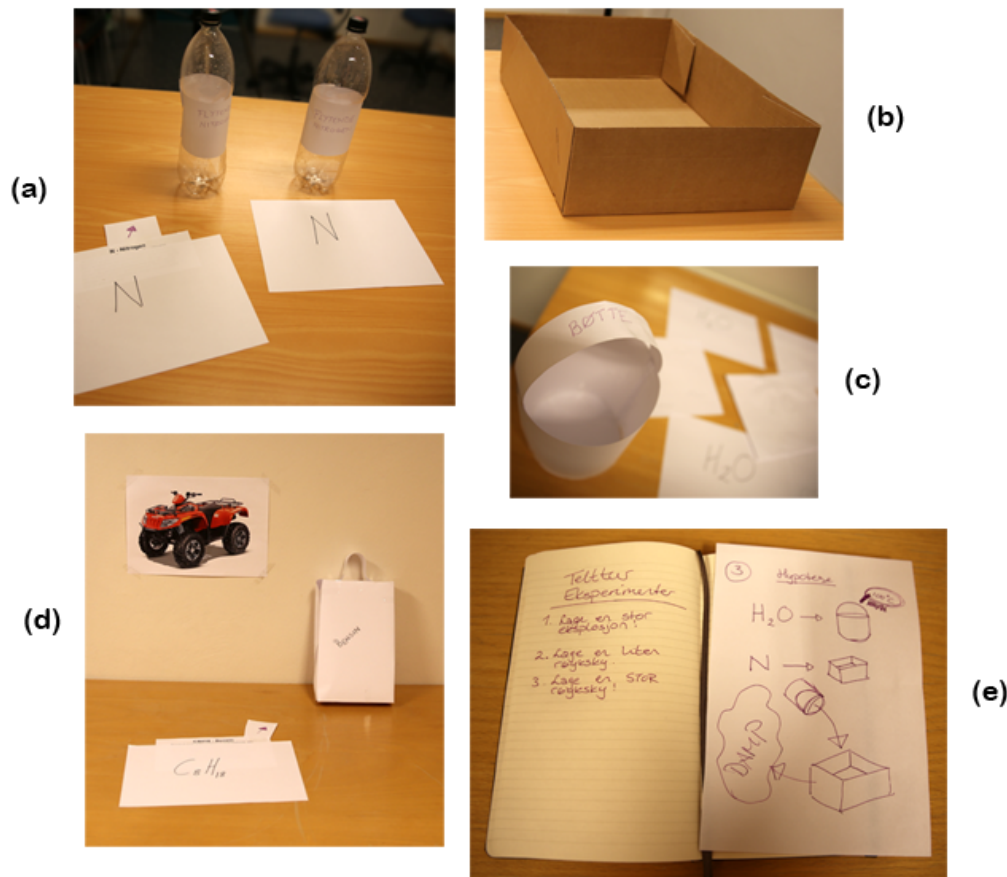
Figure 4.6 (a) Nitrogen bottles and information about Nitrogen, (b) nitrogen container, (c) a bucket of water and papers indicating a lake, (d) print of an ATV, paper fuel can and information about octane and (e) a book with experiments and a hint.

Based on the conceptual design and user feedback from low fidelity user tests, an interactive, high fidelity prototype was created. This prototype was developed using Unity 5.4.1[12], Microsoft Visual Studio 2015 [13](is installed when installing Unity) with C#, Autodesk 3D Studio Max 2014[14], Adobe Photoshop CS5.5 [15]and Adobe Flash Professional CS 5.5 (renamed to Adobe Animate CC [16]in November 2015 [29]). Other tools that can be used for VR projects are Unreal Game Engine, Autodesk Maya 2017 and Adobe Illustrator CC. Both Adobe Flash Professional CS 5.5 and Adobe Illustrator CC are tools for creating vector graphics, and either tool could have

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[12] Unity: https://unity3d.com/

[13] Microsoft Visual Studio: https://www.visualstudio.com/

[14] Autodesk 3D Studio Max: http://www.autodesk.com/products/3ds-max/overview

[15] Adobe Photoshop: http://www.adobe.com/no/products/photoshop.html

[16] Adobe Animate: http://www.adobe.com/products/animate.html

been used in this project. In principle, the tools were chosen appropriate based on familiarity and previous knowledge and accessibility.
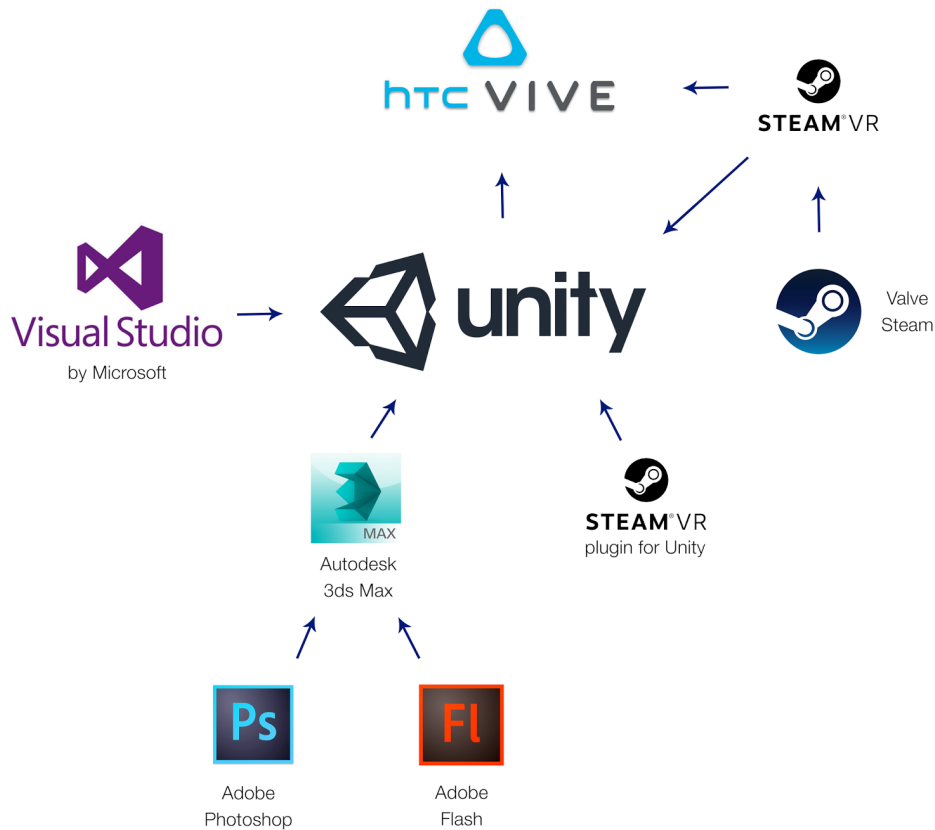
Figure 4.7: Software technology stack for the VR solution

Developing and Debugging in Unity

An Apple MacBook Pro 15", 2,6 GhZ Intel Core i7, 16GB 1600 Mhz DDR3 with the operating system Microsoft Windows 10 was used when creating the basic test scene in Unity 5.4.1 with SteamVR plugin. Unity can be run on both OSX and Windows. However, Unity on Windows was chosen due to personal preferences. The SteamVR plugin, developed by Valve Software[17], is used for developing VR experiences with Unity. SteamVR from Steam must be installed to make the SteamVR plugin for Unity to work with the HTC Vive. Due to the fact that SteamVR installs specific files that are used by Unity and the SteamVR plugin. Microsoft Visual Studio 2015 was used for the development process with C#. HTC Vive requires an NVIDIA GeForce™ GTX 1060 graphics card (or equivalent or better) [100]. The MacBook Pro did not have such a graphics

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[17] Valve Software: http://www.valvesoftware.com/

card. Therefore an .exe file was built for each code testing. The .exe file was executed on a computer with an Intel ® Core (™) i7-5820K CPU @ 3.30 GHz processor with 16 GB RAM and running Microsoft Windows 10, 64-bit. However, the .exe file does not support debugging. Working in this matter was fine at the start of the development, but later on debugging proved to be necessary. Thereby, to ensure version control and backup the project was pushed to a repository on GitHub [101]. Development continued on the computer with the 3.30 GHz processor, which allowed running debugging directly from Unity and Microsoft Visual Studio. Furthermore, the Lab Renderer was added to the VRBS. The Lab Renderer, by Valve Corporations, is a set of scripts and shaders that contribute to maintaining the frame rate in VR [102]. Hence, by maintaining the frame rate, motion sickness can be avoided [103].

Setting up the Forest scene

The forest scene was created in Unity 5.4.1 by the software's premade tools and objects. With the terrain function in Unity the ground, grass, and trees were created. Then with the function WaterBasicDaytime the lake was created. In Unity the terrain had to be converted to mesh for the Lab Renderer to work.

Creation of 3D objects

An Acer Intel(R) Core(™) i5-4210U CPU @ 1.70 Ghz, 8GB RAM with the operating system Microsoft Window 10 was used for designing the scene in Unity 5.4.1 and for creating 3D models in Autodesk 3D Studio Max 2014. Some models were also downloaded from the Unity Assets Store[18] and from TF3DM[19], which is an online site where you can download 3D objects for free.

The Nitrogen Canister as seen in Figure 4.8 below, was modeled with Lines by using a picture as measurement. Lathe and Extrude was added in order to create the canister. For the texture with the name "Flytende Nitrogen" Adobe Photoshop was used. The Nitrogen container was created with splines using Loft and Shell. Then polygons were moved and Smooth Modifier added.

Other 3D models that were created in 3D Studio Max are: The disposable grill, Professor's book, the tent, Molecules, Nitrogen Atom and Information Signs (See Appendix I). Professor's book had textures created in Adobe Photoshop and Adobe Flash. The written textures explaining the experiments were displayed with a font that supposedly illustrated the

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[18] Unity Assets Store: https://www.assetstore.unity3d.com/en/#!/

[19] TF3DM: http://tf3dm.com/

professor's handwriting. The hint illustration textures were simple drawings showcasing that the professor had made them.

All models were saved with several versions in 3D Studio Max and also in Dropbox[20] as backups. In addition to being saved on the computers used during development.
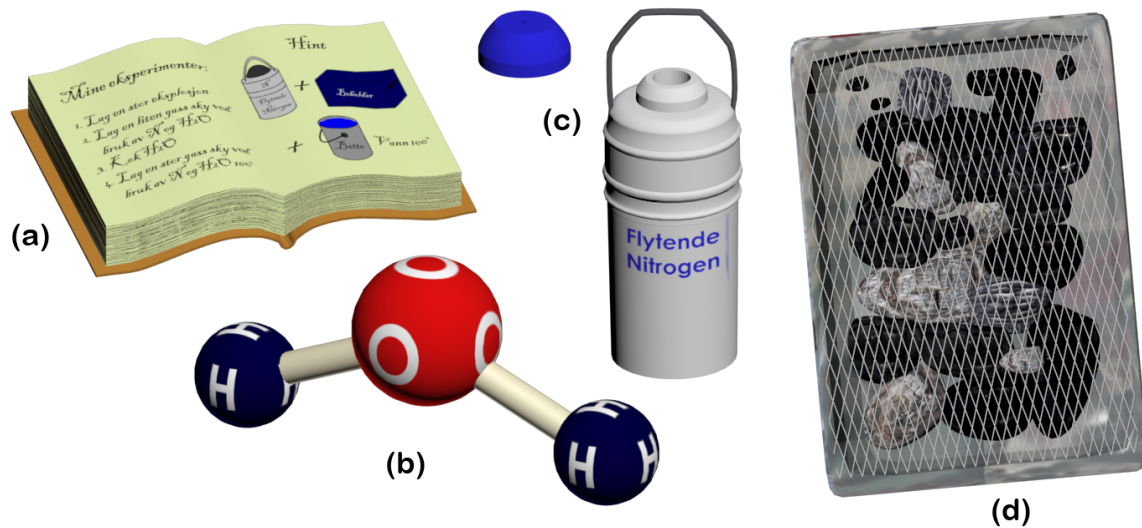
Figure 4.8: Some of the 3D objects that were created: (a) Professor's book, (b) H_2O molecule, (c) Nitrogen Canister with a lid and (d) the disposable grill.

Teleporting in the Forest Scene

In order to afford the user in moving through a larger area than the physical space the plugin Vive Teleporter[21] by Flafla2 at GitHub was added. The user can push the touchpad in order to see a blue stippled arc with an orange circle in the end. Figure 4.9 shows a user teleporting. The arc shows the angle and the orange circle shows where the user will be teleported when releasing the touchpad.
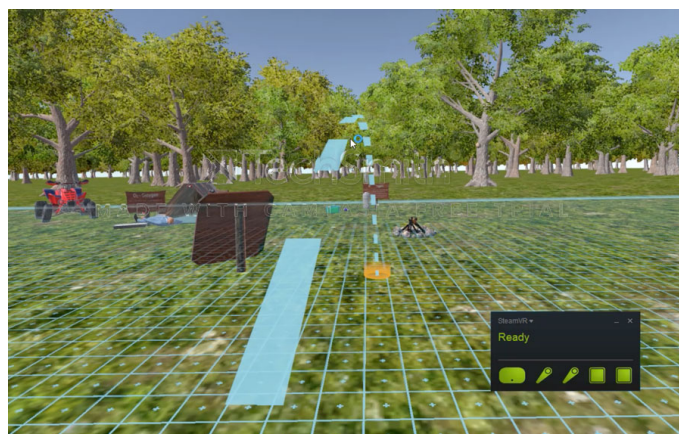
Figure 4.9: The user teleporting in the scene with the Vive Teleporter plugin

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[20] Dropbox is a file hosting service that offers storage in the cloud and file sharing.

[21] Vive Teleporter by Flafla2: https://github.com/Flafla2/Vive-Teleporter

Making the Professor Communicate

The professor spoke to the participants throughout the entire VRBS. The professor explained to the participants how to pick up objects and how to find the notebook. In addition, he would talk about various substances once the user had activated an object. If the users did not progress in the tasks, the professor would give hints that supported the users in completing the tasks. When an experiment was complete, the professor would shout "EUREKA". An audio recorder was borrowed, a script was written (see Appendix D) and time and place for the recording with an actor was scheduled.

4.2.3   Supporting Different Learning Styles with the VR Based Solution

Several elements and functionalities were added to support the students in several learning styles. Audio clips where the professor explains the various substances were added, as well as displaying a sign with written text about the same substance. The audio clips and signs would have different information that could possibly help the students in completing the tasks. Consequently, by adding these elements, the students with an *aural learning style* [1] will be supported. In addition, 3D models of the various molecules and atom were added. When the user touches the molecules or atom with the controller, they can pick up the molecules and atoms by pressing the controllers trigger button. By using the controllers, the students can move around the scene, pick up objects and combine them with other objects. All these elements support students who have *visual and/or kinesthetic learning styles* [1]. Furthermore, the students have to solve the tasks either by themselves or in a classroom with their classmates, which can be supported by Gardner's Multiple Intelligences [15] for example *People-Smart* and *Self-Smart* students. Since the scene is in a virtual forest similar to a real forest it can support the *Nature-Smart* intelligent students. In addition, the participants have to use reason and logic in order to understand how to perform the tasks. Hence, the *Logic-Smart* students' intelligence is supported.

4.3   Testing and Evaluation

For this research the following research methods have been chosen:

- Interviews
- Direct observation with Think Aloud Technique
- Questionnaires

Several user tests were conducted to see if the junior high-school students in the population had an enhanced learning experience with the VRBS. The low-fidelity prototype was tested with five participants and the high-fidelity prototype was tested with twelve participants.

4.3.1 Low-Fidelity User Tests

The low-fidelity prototype was used to determine that the participants were able to complete the tasks effectivly. The goals for the user tests were:

- Tasks needs to be approved by the teachers
- The participants have to understand the user tasks
- The participants are able to complete the user tasks
- Find the intuitive placement for the objects

The user tests were conducted with direct observation in a controlled environment, with the think aloud technique. Five participants were recruited for the user test: three science teachers and two students. A specific time, day and location was agreed upon for each participant. The location for the controlled environment was a group room at the University of Agder in Grimstad. The group room was booked via the University's webpage. Sometimes, students might pop their heads in the group rooms to check if they are available, which could disturb the participants during the interviews and tests. In order to avoid this, a sign was taped on the door saying "Brukertesting pågår". The sign solution was successful. The teachers were asked to sign a consent form upon arrival. During the scheduling of the students for the test, the parents were contacted and asked for approval before talking to the students. Once the parents and the students had approved, an e-mail with a consent form attached was sent to the parents. The students were asked to bring the signed consent form and deliver it upon arrival to the test location. The consent forms allowed video recording of the participants during interview sessions and the test.

Figure 4.10: Low-fidelity usability testing

The interviews and tests were video recorded with a Canon EOS 5D Mark III with a Tamron lens SP 2470mm and a Velbon® tripod, to avoid any disturbance like shaking during the recording. The participants were asked to wear a slalom helmet with a mounted GoPro™ action camera, to video record what they were looking at and how they were moving through the environment. Thereby, making it possible to analyze what they were looking at based on given user tasks. In addition, the helmet and slalom goggles made the participants anonymous. Hence, some pictures from the tests could be used in the research. All of the participants agreed upon being video recorded and to wear the slalom helmet with an action camera and goggles.

4.3.1.1 Interviews

Interviews (See Appendix F) were conducted both before and after the user test. The teachers were asked if they would like to use a VR tool in their science class; if such a tool was available. All of the teachers answered yes, and explained that it would be extremely beneficial for the students to actually see the molecules and allow them to do any experiment without the risk of getting hurt. The teachers were also asked what they thought about the experiments that were chosen for the VRBS. All of the teachers answered that they liked the experiments and that they would like to do these kind of experiments with their class. Since they are not able to do so in real life because of the danger and the lack of various resources. The students were also asked if they would like to have VRBSs available in a science class. All of the students answered yes. They explained that with VR they could conduct dangerous experiments without the risk of getting hurt. Furthermore, they stated that they would be motivated to pay more attention in class if a VRBS was available.

4.3.1.2   Evaluation from the Low-Fidelity Usability Test

The video recordings from the user tests were analyzed and evaluated manually. There were five participants for the user test. Three participants were science teachers between 30 – 50 years of age where one of them were female. Two participants were male students between 13 – 16 years of age. The younger participants from early junior-high school needed more help than the older students. To avoid the users feeling stupid, inadequate or getting stuck, the facilitators were quick to give them guidance or hints in the book if they said that they did not know what to do, or if they stood still without trying to solve the tasks. Hence, all the users were able to perform the tasks. The participants were asked if they were willing to wear a slalom helmet with an action camera attached (for video recording) and slalom goggles (for anonymity). All the users accepted to wear the equipment. One of the users found it difficult to orientate in the room and to find objects when wearing the goggles. In order to make it less challenging for the participants, they could have been told that the helmet and goggles could be removed if necessary. In addition to blurring the participants' faces in the video recording.

Assumptions before the tests were that the users would put out the campfire by pouring a bucket of water over it. The campfire is necessary to perform task #1 and #3. Therefore, an inextinguishable torch was placed near the campfire, so the user could set fire to the campfire if they had extinguished the fire. During the first user test, the torch was confusing to the user who though it was to be used as a tool for every experiment. In addition, the participant never put out the campfire. Hence, the torch was removed to avoid any confusion during the next user tests.

Figure 4.11: To the left: Slalom helmet with goggles and the mounted action camera on top. To the right: The inextinguishable paper torch

All of the participants, except from one, walked back and forth between the professor's notebook and the objects. The other participant took the hint sheet from the book and walked around with it during the tasks. This resulted in he/she finishing the tasks faster than the other participants. For this reason, in the high-fidelity prototype the book with tasks and hints will always be available for the user on the left hand controller. For future work, the user will be asked if they are left or right handed. The placement of the book will be determined by the input response from the user. All the participants were able to complete the first experiment (create a huge explosion) without any hints. The two experiments with the use of nitrogen and water were tasks the users needed hints in order to resolve them. The hints were illustrations of drawings showing the user how to perform the tasks. Every participant were able to understand the illustrations, hence they successfully completed the given tasks.

For the second task, vapor cloud was written as the reaction between nitrogen and water, assuming this was the correct term after reading in the science textbook for teachers. One of the participants (a science teacher) informed that it should be called a smoke cloud instead. Therefore, the text was changed to smoke cloud. During the next user tests the participants thought that the smoke cloud would be created when they put out the campfire. Another participant was asked, also a science teacher, what the cloud should be called. The participant said that the word gas cloud would be a more accurate name for the reaction between nitrogen and water. In addition, the user informed that during science classes at school the students are well informed about the different characteristics of substances, like solid, liquid and gas. Thus, the name was changed from smoke cloud to gas cloud. In addition, the description was changed to: "Create a gas cloud by using N". Thereby, the users also got an indication of how to perform the experiment. Observing that many participants had trouble with the third experiment (Create a huge gas cloud by using N"), another experiment was created for the high-fidelity prototype. The new experiment was to boil water. Then the last task was to create a big gas cloud by using N and H_2O $100°C$.
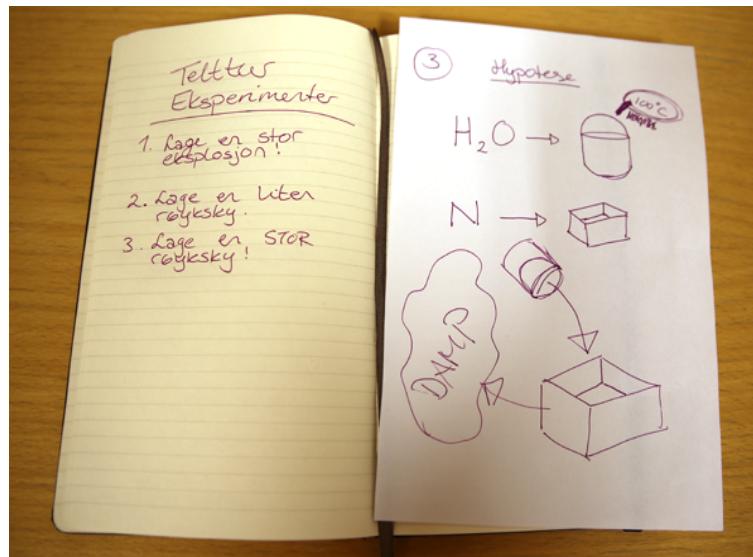
Figure 4.12: The professor's notebook with the list of experiments on the left page. On the right page is a hint for the third experiment.

To be able to illustrate that the molecules would show up when the user pointed at objects in VR, one of the facilitators was standing next to the participants with sheets of paper with illustrations of molecules. When a participant looked at an object, the facilitator would show them the sheet of paper illustrating the corresponding molecule. One of the participants took the paper and wanted to bring it along. This was an unforeseen experience. The facilitator allowed the participant to take the papers, but took them back as soon as the participant started to move. Furthermore, in order to indicate liquid Nitrogen, empty 1,5l soda bottles were used. The soda labels were removed and a taped note was added that said Liquid Nitrogen. Most users unscrewed the soda bottles cork in order to pore an imaginative Nitrogen liquid. This was unforeseen since it was assumed that the participants would simulate poring nitrogen without unscrewing the corks.

The paper objects in the scene did not have a correct scaling to the real world, which seemed to confuse the participants. The tent and the professor had a very small size in regards to other objects and to the participants. In addition, many participants did not understand that there was CO inside the tent because of the disposable grill. Assuming that the size would not be a major issue, and to avoid using too much time creating the scene, some objects were smaller than the real world. Many participants had trouble finding the tent and the professor. Hence, the facilitators had to guide them in order for them to find the objects. Therefore, a small note was attached to the disposable grill with the text: "CO" and taped to the grill. For future prototype testing facilitators should consider creating more accurate scaling of objects. Thereby, it might be easier for the usability testers to find and use the paper objects correctly. In order to

illustrate a man (professor), a paper stick figure was cut out. Several participants were unable to understand that this was a person. Therefore, a face was drawn on the paper figure including glasses and some hair. During the following user tests there were no problem for the users to understand that the paper figure was the professor.

Moreover, there were several sheets with information about different chemicals. These sheets were placed behind the corresponding sheet containing the chemical formula, for example H_2O for water. The sheets were made visible showing a headline and the first sentence. Although the first participant made a thorough orientation in the scene, he/she never viewed the sheets information. For that reason arrows were placed on the sheets pointing upwards, indicating that the sheets could be moved in order to read additional information about the chemical. Which resulted in one of the participants pulling out the sheets to read about the chemicals. Hence, being able to complete the tasks.

A container was placed next to the water and a bucket next to the nitrogen bottles. The idea was that the users would fetch water with the bucket and pour nitrogen into the container. The placement of the items was confusing for the first participant during the user test. Therefore, the bucket was moved next to the water and the container next to the nitrogen. During the next user tests the participants interacted with the items that were placed next to the objects. Thus, supporting the participants to complete the tasks effectively.

Figure 4.13: To the left: The professor in the tent with a disposable grill and carbon monoxide.
To the right: The chemical formula for Nitrogen. Underneath is a sheet of paper with more information
and an arrow indicating more information can be found.

It was important that the science teachers approved the tasks, since most of the tasks were created from the teacher's textbook. In addition, the teachers had to confirm that the molecules and text information about each substance was correct. The teachers also had to approve of the

nitrogen atom's construction. All the participants understood and completed the tasks. Furthermore, they thought the tasks were useful and fun to perform. Also, the teachers approved the tasks. Hence, the development of the VRBS could continue.

4.3.2   Usability Testing

A pilot session was conducted approximately a week before the usability test. The participant discovered various issues that were addressed. For example, the participant explained that he/she did not feel included in the VRBS. He/she was only completing tasks. Thereby, an audio clip was added, where the professor says: "Why did this reaction happen?". When the audio clip plays upon completion of a task, the user has to say out loud what he/she thinks is the correct answer. When the user answers the professor, he/she reflects over the observed chemical reaction. See Appendix K for further suggestions for improvements.

The participants for the test were junior high-school teachers and students. Usability tests were conducted to make sure that everything was working correctly and that the users did not experience motion sickness during the VR test. Most importantly the teachers could inform if something was incorrect, or if anything should be changed in regards to the syllabus. The usability test consisted of six participants. The test took place at the UiA in a classroom with at least 3x3 meters available floor in a controlled environment. VR equipment was installed and tested before the usability test. The test was conducted for determining if the product worked correctly, the users understood how to perform the given tasks and if they were pleased with the experience.

The user tests were conducted at the UiA due to accessibility and support. The VR equipment is heavy and it was more convenient to move all of the equipment between classrooms instead of location. In addition, in case of any technical issues, there would be access to technical support at the University, which might not have been the case at a different location. However, this made it challenging when recruiting users for the user tests since the students and teachers had to travel to the University.

4.3.2.1   Procedure

Four participants were asked to contribute. Two science teachers and two junior-high school students. The recruitment took place via e-mails with the headmaster at a junior-high school. The headmaster asked science teachers and students if they wanted to participate. Since, the students and teachers were busy with exams they were not available to participate. Another recruitment was made between a science teacher and a facilitator via e-mails

Before the high-fidelity usability test a small pilot study was conducted with two participants in a classroom at UiA. One participant was a teacher at UiA, the other was a student and not from the sample target. The pilot study took place to make sure that the VRBS worked accordingly and that the participants were able to do the tasks.

The usability tests were conducted at UiA in a group room as a controlled environment with direct observation and the think aloud technique. The HTC Vive equipment was installed in the room.

Figure 4.14 Participant immersed in the VRBS

First, the facilitator had an interview with the participant asking them a few questions (see Appendix F). One of the facilitators was filming the participants' interview and the interaction with the VR gear with a Canon Eos 5D mark III and a Velpon tripod. The interview was video recorded with the camera lens pointing to the back of the participant. Hence, keeping the participant anonymous. Then the participants experienced VR with Tilt Brush in order to get familiar with being in a VR environment with the HMD attached and to learn how to use the controllers. Afterwards, the participants received a sheet of paper (see Appendix E) with information about a professor in a tent who needs their help. Then they were informed about how the controllers worked, that they had to stand still when the professor was talking and also answer out loud the professor's questions. Furthermore, the facilitator told them about the grid in VR, that you can teleport while holding an object and to use the think-aloud technique. When the VRBS was running, the facilitators could watch on the computer monitor what the users were seeing in the HMD. A screen and audio recorder program (Camtasia[22]) recorded the sessions on the computer monitors. One of the facilitators helped the participants with attaching the HMD and Bose Quiet Comfort 15 headphones. The headphones had acoustic noise canceling,

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[22] TechSmith Camtasia: https://www.techsmith.com/tutorial-camtasia-8.html

thereby avoiding outside noise disturbing the participants. Then the facilitator explained how the VRBS works and how to get started with the test. The first task the participant had to perform was to drag the professor out of the tent in order to help the man receive oxygen. Then the professor would talk to the participant asking to help him finish his experiments, since the professor was not feeling well after inhaling carbon monoxide from a disposable grill inside the tent. The professor informed the participant that the experiments could be found in his notebook by using the left controller. The first task in the book was to create an explosion by putting gasoline on the campfire. The second task was to make a gas cloud by pouring nitrogen in the lake. The third task was to boil water with the use of a bucket and the campfire. Then the participant had to pour nitrogen in a container and pour the boiling water on the nitrogen. Thereby, performing the last task, which was to create a huge gas cloud.

After the participants had done the tasks in the VR system they were asked a few questions in a second interview. The interviews were video recorded with anonymity. The teachers were asked if the students find chemical bonding difficult, if so how many in a class and what the teachers thought could be the cause. They answered that around 30% of the students find it difficult because the teaching methods are too abstract and too much theoretical work. The teachers also expressed that they would like to use a similar VRBS in their chemistry lectures, if available.

The students were asked if they had learned about chemical bonding in the chemistry class at school. They responded that they did not know what chemical binding was. The interviewer explained what chemical binding is, then the students confirmed that they have learned about it at school, as well as confirming that they find the topic to be difficult. The students were also asked if they would like to use a similar VRBS in a chemistry class. They responded that they would look forward to come to chemistry class if they knew that they would be using VR instead of regular lectures. One of the students said: "I learn better when learning is fun". They also confirmed that they would achieve a better understanding of the subject if they could use VR in the lectures. A connection can be drawn between these results and intrinsic motivation from Malone and Lepper, when the students have fun while learning it will lead to intrinsic motivation since they are engaged in the learning for their own sake [2].

Even though the VRBS should be used collaboratively at school, for the usability tests there was only one participant at a time. No other participants were watching during the test, to ensure no disturbance. In addition, avoiding the participants trying to impress each other. Hence, it would be possible to test if the users learned quickly how to use the system. Before the test started the facilitators explained to the participants that they wanted to test the VRBS and not the

participants themselves. The science teachers signed a consent form (see Appendix C). For the students their consent form had been signed by their parents and delivered to their teacher, who delivered it to the facilitators (see Appendix B). Then the facilitators asked if they had any questions.

Some days after the user tests, one of the teachers from the user test sent us an e-mail. The e-mail stated that the students who had tested the VRBS was very pleased with the experience, and had told other students about the system. Those students had expressed that they would also like to participate in the user tests. Unfortunately, they were not able to participate for the next user tests due to exams.

4.3.2.2 Usability and User Experience Goals

The usability goals for week one are:

- *Safety*: The product works without critical errors
- *Learnability*: The system is learned quickly
- *Effectiveness*: The users are able to complete the tasks

Including *User Experience Goal:* The users are pleased with the experience

Products functionality

The VRBS has to work without any errors that might disturb the participants when performing the tasks. Hence controllers, headgear, sensors and audio headset have to function. In addition, the VR learning experience system has to work without any errors. The participants should understand how to use the system. And especially, to make sure that none of the users experienced motion sickness while using the product.

Learnability

In order to perform the tasks, the system has to be understandable for the user. Thus, that the users understand how to use the controllers, teleport and manipulate objects in an effective and efficient manner. Furthermore, the users should be able to see and read the signs with the information about the various substances.

Task completion

The participants are able to complete all the tasks without assistance from the facilitators.

Overall experience

The participants have to experience the VRBS with tasks and scenes that they find pleasurable. Consequently, that the participants wants to continue exploring and performing tasks, and do not want to quit before all the tasks are completed. In addition, determining if the users were fully immersed in the VRBS.

4.3.2.3 Results from the Usability Test

SAFETY

During the user tests some bugs were encountered in the system. The facilitators took notes for all the bugs and explained them to the participants. As an example, at one point there were two sounds playing simultaneously. One of the sounds was information about liquid nitrogen that might help the participant in finishing an experiment. The participant did not hear the information because another sound was playing at the same time. The participant was informed that there was a bug in the system that led to two sounds playing at the same time, and was given the information about the liquid nitrogen, which helped the participant in finishing the experiment. Furthermore, when the user touched the nitrogen bottle the audio clip played. Participants would then have to remove the lid from the canister to be able to use the liquid nitrogen. Another audio clip started playing when the lid was removed. However, several users immediately removed the lid from the canister, which resulted in the audio clips playing simultaneously. Therefore, to address the issue the audio clip for opening the canister was removed. The audio clip for the lid informed the user of the temperature for liquid nitrogen. Consequently, the audio clip was removed and the temperature information was added to the sign about nitrogen instead.

Additionally, when the participants boiled the water in the bucket, they placed the bucket inside the campfire. Accordingly, because of a bug, the flames from the campfire were attached to the bucket. As a result, the participants carried a bucket of water that was on fire.

Some of the participants found it hard to understand how to teleport and when to do so in the scene. This resulted in some participants' crashing/bumping into tables and walls in the real world. No one got hurt, but the participants became more careful when moving in the scene and that sometimes restricted the overall experience. In addition, those participants who struggled with the teleportation used more time to perform the experiments. Therefore, a sign that informed the users how to use the controllers was added and bugs were addressed.

Moreover, an empty room would have prevented the participants in crashing/bumping into objects.

LEARNABILITY

The younger participants found it easier than the older participants to interact with the HTC Vive Controllers. The students, who are within the target sample, understood quickly how to teleport, pick up objects and do experiments. When the participants started the VRBS they were asked to pull the professor out of the tent. Inside the tent is a used disposable grill. When the participants touched the grill with the controller an audio clip about carbon monoxide was played. In addition, a sign with information about the substance and the molecule was made visible. None of the participants from the usability test picked up or touched the grill. Therefore, the professor was placed further inside the tent and the grill was placed in front of him. Hence, when the user is going to pull out the professor they have to move the grill first.

Signs with information about specific substances were added around the scene. The sign for a specific substance would be visible once a participant had touched the object with the controller. However, it was noticed that the overall participants did not see the signs because they were looking downwards or directly at the object when activating the sign. The issue was addressed by changing the signs to smaller signs next to the objects on the ground.

Figure 4.15: 3D model of a sign displaying information about gasoline

The professor's notebook is visible when the users press the trigger button on the left controller. The book will be attached to the participants left controller whenever the trigger button is pressed. Once it is released it will disappear. During the usability tests, several participants tried to turn the pages of the book. Hence, it can be claimed they were kinesthetic learners. In order to support the learning style more pages and experiments can be added for future work.
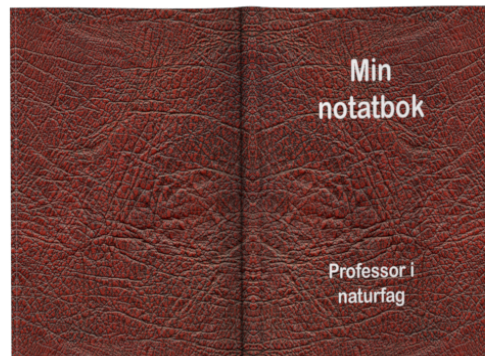
Figure 4.16: The cover of the Professor's book

EFFECTIVENESS

A list of experiments was displayed in the book, ranged from number one to four. From the numbering it was expected that the participants would perform experiments in chronological order, starting with number 1. Nevertheless, during the usability test the participants started at random experiment and did not finish them in a chronological order. Thereby, the participants got confused on which experiment to do next and if they were finished with the VRBS. Therefore, the textures in the book were changed. When one of the tasks is completed, it will be crossed out in the book. Thus, indicating that the experiment is done.
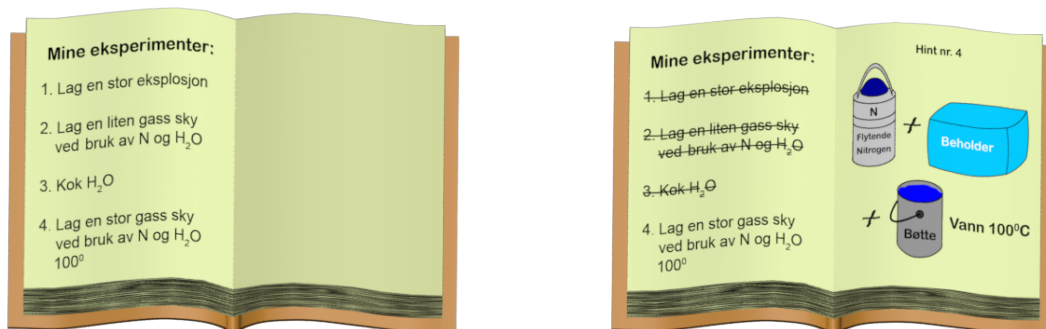

Figure 4.17: To the left: the book with experiments.
To the right: the book with experiments 1-3 crossed through and with a hint for task #4.

One participant would have made all the tasks without the facilitators help if the book with the hint had worked correctly. The hint for one of the experiments did not show up in the book. The facilitator had to explain to the participant what the hint looked like, which helped the participant to solve the task. This issue was addressed for the next user tests.

The molecules were attached to the corresponding object. If the participants wanted a closer look on the molecule they would have to pick up the object with the attached molecule. However, several participants tried to pick up the actual molecules instead. This feature was changed to allow the user to pick up the actual molecule. Hence, supporting the kinesthetic learning style.

USER EXPERIENCE

All of the participants were pleased with the experience, except one. One participant had been dreading the usability test and was very nervous. The reason was due to the fact that the participant did not know anything about virtual reality or how to use the VR system. The participant had signed the consent form where information about the test and the reason for the test was explained. For that reason it was not explained in detail before the usability test how the VRBS worked. Overall information was the only thing that was provided. Nevertheless, the participants were told that they were not the test subjects, but they were going to assist in testing the actual VRBS, and not how the participants performed. Furthermore, the participant did not have any questions after the introduction. The other participants, on the other hand, were extremely positive to the experience. Quotes such as "This is really cool" and "wow" was heard frequently. Thus, they were immersed and experienced the wow-factor.

All of the participants were immersed in the VRBS; some more than others. One of the participants was afraid to throw the gasoline can into the campfire, and approached it very carefully. When the gasoline can hit the campfire it initialized an animation of an explosion, as well as playing an audio clip of an explosion. All of the participants flinched when this happened.

Overall, the younger participants learned quickly how to use the controllers, teleport and manipulate objects. All the tasks were completed and all of the students had fun while doing the tasks. In addition, they were immersed in the VRBS.

4.3.3 Testing the Learning Experience

When the VR system was tested and found functional, there was a need to figure out students' experience while interacting with the VR environment. The HTC Vive was set up the first day, several hours before the test. Then there was sufficient time to prepare for the test before the participants arrived. One minor pilot test was conducted, in order to check that the system worked and that it was possible to perform the experiments. The Learning Experience Test was conducted in a controlled environment with direct observation and the think aloud technique.

4.3.3.1 Procedure

One pilot session was completed and proven successful. Nine participants were asked to test the VRBS. The first day there were one teacher and two students. For the second day there were one teacher and five students. The recruitment took place with the help of a teacher via e-mails and the leader at Vitensenteret Arendal who made calls to the headmaster and teacher at a junior-high school.

First the participant experienced VR with Tilt Brush in order to get familiar with a VR environment, in addition to the HMD and controllers. The Tilt Brush experience worked as a very nice transition for introducing the VRBS.

The junior high-school students received a questionnaire sheet, with open and closed questions, before and after using the VRBS and discussions with a teacher. The questionnaires contained questions regarding the chemical experiments the students would encounter during the VRBS. Furthermore, they were asked about motivation in regards to performing chemical experiments in VR and if they would like to use a VR solution in a chemistry class. The purpose with the questionnaire was to determine if the students had a positive experience with the tool, if they learned something when performing the chemical experiments and if they could envision using the VR tool in the classroom. See Appendix G for the questionnaires.

After two students had tested the VRBS, they sat together with a science teacher and discussed the VRBS. The teacher was handed a set of questions about the tasks the students did in the VRBS. The students had to explain how they solved the tasks and why the chemical reactions happened. Then the teacher gave them additional information about the chemistry that they could later use in the second questionnaire sheet. The next day there was two students and then three students who did the same procedure with another teacher.

4.3.3.2 Learning Experience Goals

The goals for the Learning Experience Test consist of parts related to the research questions. They are also a product of Kolb's experiential learning cycle. The participants are able to perform tasks without assistance from the facilitators by having a concrete experience. The participants will be actively engaged in the VR environment and participants will observe and reflect upon chemical reactions through the use of VR.

Concrete Experience

The participant must be capable of performing the tasks from the professor's book in the VR environment. If the participant needs to use hints from the book in order to complete the tasks,

the performance is still accepted. Although, if too many participants have to use hints and if they have to use all the hints, then the performance outcome will be degraded. In addition, that the participant is able to explore the VR scene and manipulate objects. With the use of PBL and SCL concrete experience can occur, hence participants gain experience when performing tasks. For this usability test, the goal is a completion rate of 100% for each task.

Engagement

The participant has to be actively engaged in the VR environment. Meaning that the participant is trying to perform the tasks by using objects and exploring the scene. If the participant is not engaged and motivated in the environment and wants to quit the test before trying to do any tasks, then the usability goal of engagement has failed. In order to keep the participants in their own flow zone with ZPD and fun elements, the participants should experience engagement and motivation. In addition, when the participants have completed all the tasks they want to explore more in the scene or receive new tasks to perform.

Observing and reflecting

From Kolb's experiential learning cycle, the students should observe and reflect upon their experience with the VRBS by answering the professor's questions, the teacher's questions during discussions and when answering questions in the questionnaire sheet after the teacher's discussions. After successfully performing each experiment the professor ask the participant why did this chemical reaction happen. Then the participant has observed the chemical reactions and reflects upon the experience both in the VR scene and during discussions with the science teacher. Moreover, reflecting over their experiences in the VRBS when answering the questionnaire sheet. If the participant is not able to answer the professor, contribute in the discussions with the teacher or give answers to the questions on the questionnaire sheet, then the reflection and observation has failed.

5   FINDINGS AND RESULTS

The learning experience goals from the research questions and hypothesis addressed in chapter 4 were Concrete Experience, Engagement and Observing and Reflecting. The results and findings are listed below.

5.1   System Design & Development

The target sample, students between 15-16 years of age, were asked in the questionnaire on a scale between one to five, where one is very hard and five is very easy, how was the difficulty for the tasks in the VRBS. As seen in Figure 5.1, 71,4% of the students thought the difficulty level for the tasks was average. Hence, the students found the tasks neither too hard nor too easy. Thus, the students were capable of completing tasks with assistance from hints in the VRBS. Thereby, ZPD was achieved.
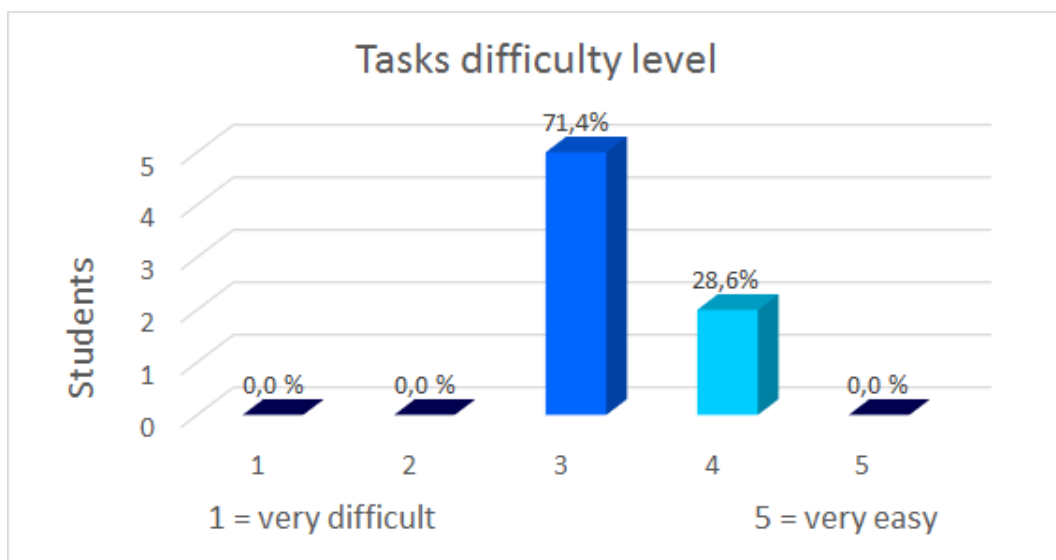

Figure 5.1: 71,4% of the students thought the tasks difficulty level was average

Moreover, the students were asked on a scale between one to five, where one is very hard and five is very easy, how hard was it to use the controllers in the VR system. As seen in Figure 5.2, the overall students found the controllers efficient to use.
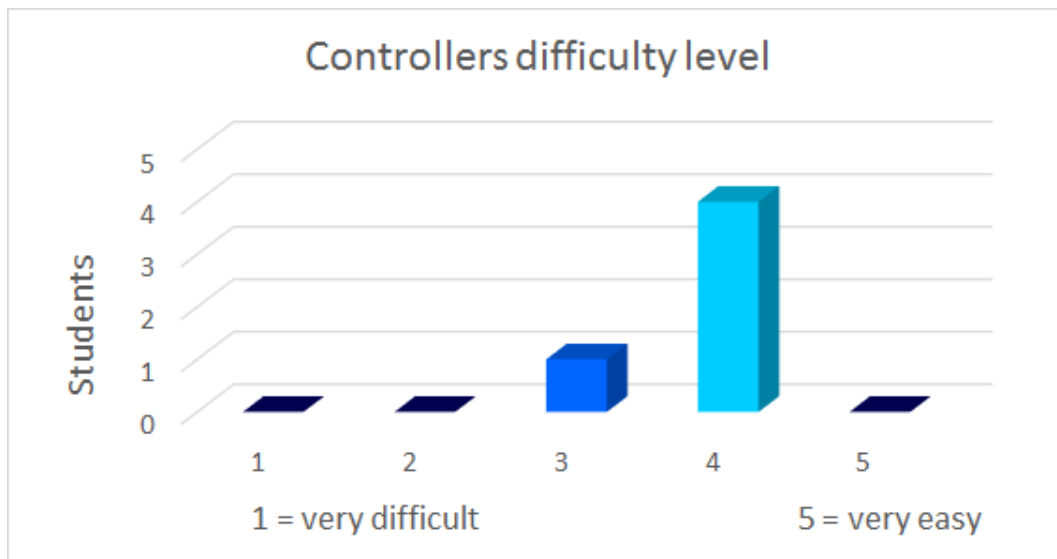
Figure 5.2: Overall, the students found the controllers to be efficient to use.

However, one of the teachers for this test was over 60 years of age. This person found the usage of the controllers to be too challenging, and used approximately the same amount of time on one task, as the other participants used on the entire VR experience. Thus, the learnability was affected by the participant's age. After the participant had finished the first task it was explained that one of the facilitators would finish the rest of the tasks, and the participant could observe the experience on the monitor instead. In regards that the teacher found the VR system to be too challenging and not a part of the target sample, it was decided to exclude the teacher from this research's overall findings.

As seen in Figure 5.3, the percentage for task completion without any help from the facilitators was 87%. One of the participants was not able to complete the second experiment.
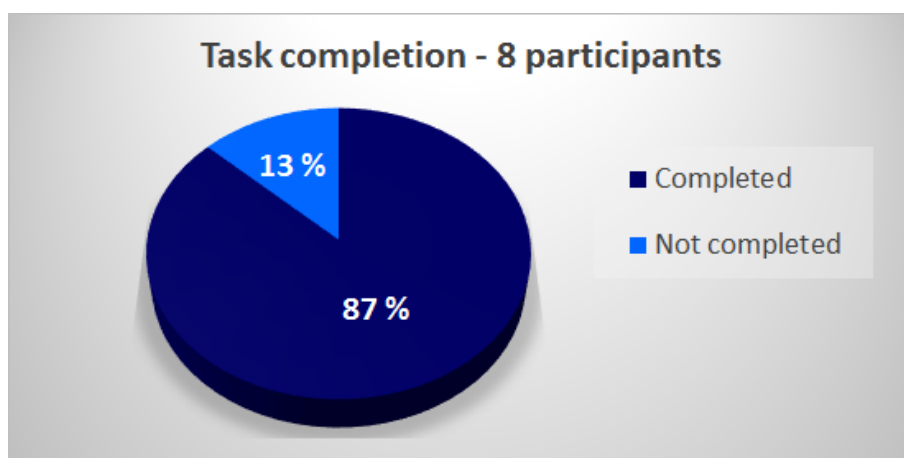

Figure 5.3: 87% of the participants completed the tasks without help from the facilitators

The hint for the second task in the professor's notebook could have been more informative. The hint illustrated the nitrogen canister and a water figure. Thus, it was assumed that the participants would be able to understand that they should pour the nitrogen in the lake. One of the participants did not understand the hint. The facilitator told the participant that the water in the hint was the lake. Then the participant continued with the third and fourth tasks, instead of the second task. After completing task 4, the participant still did not know what to do in order to solve task 2. At this point, to avoid the participant feeling stupid and awkward, the facilitator told the participant what to. Other participants fetched water with the bucket and some tried to pour nitrogen in the bucket of water, and others tried to first pour the water in the container. When the participant tried to pour cold water in the container, the professor gave a hint that the water should be boiled first. Which resulted in the participants working on the third and fourth tasks instead of the second. As seen in Figure 5.5 five of the participants solved the tasks in order 1, 3, 4 and 2, two participants solved the tasks in order 1, 2, 3 and 4, and one participant solved the tasks in order 3, 4, 1 and 2. Therefore, the hint should have had the name lake instead of water and perhaps showing some trees next to it, indicating that they did not have to fetch the water using the bucket or container for the experiment. In addition, the audio clip where the professor tells the students to boil the water should have been removed. The task completion percentage and the order for solving tasks could have a different outcome if these elements are updated.
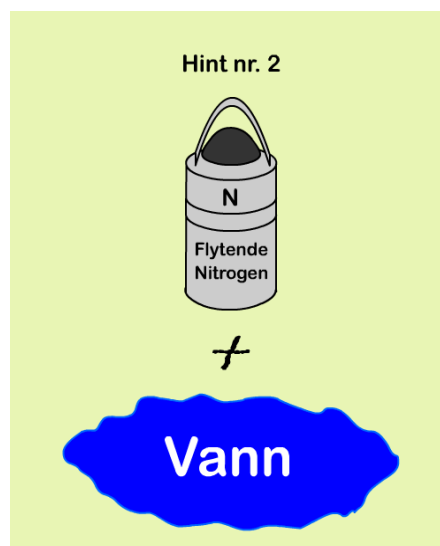

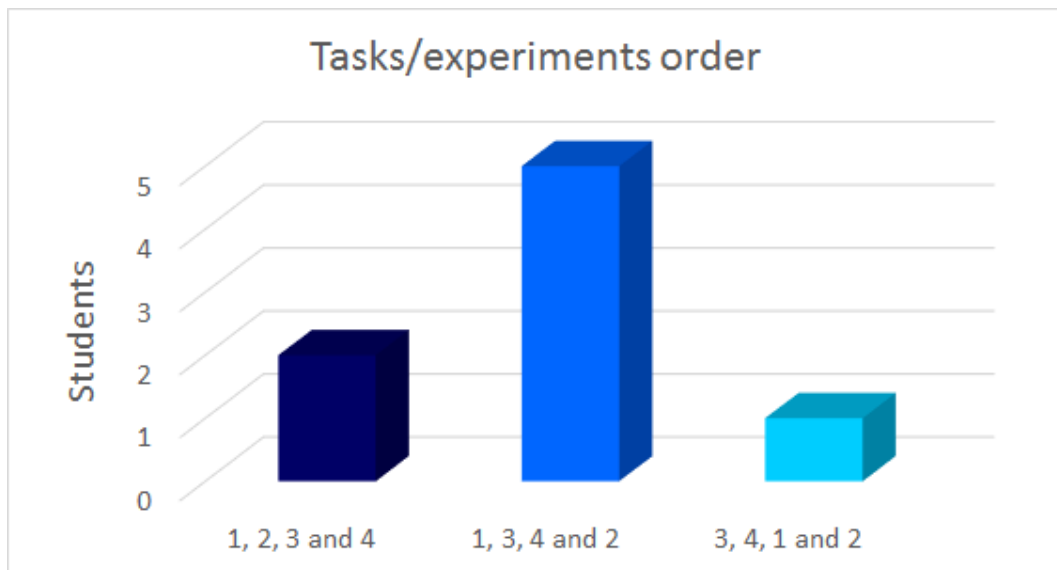*Figure 5.4: The hint for the second task*

Figure 5.5: 5 out of 8 students finished tasks in order 1, 3, 4 and 2.

Another feature was that the participants should receive information regarding CO, before helping the professor. In order to receive the CO information, the participants had to pick up the disposable grill. When picking up the grill, the professor would explain that it is a deadly gas. However, the participants did not move the grill. Instead, the professor was pulled over the grill. Therefore, the grill was moved in front of the professor and later made wider. In spite of the adjustments, the participants still did not move the disposable grill. Instead they would pull the professor over the grill. Constraints should be added to prevent the users in assisting the professor before the grill is removed from the tent. If the users try to pull out the professor, an audio clip should be played where the professor tells the users to remove the grill from the tent before helping him.

In addition, one of the participants did not notice the gasoline can until the facilitators told them to teleport to the ATV. Once the participant found the gasoline can, he/she understood how to solve the first task. The gasoline can was placed between the tent and the ATV, and behind the sign about oxygen. The can could be more visible for the participant if it is placed on the other side of the ATV.

The students were immersed and experienced the wow-factor with the VRBS. When the participants collected water with the bucket, they filled the bucket as you would in real life. With the bucket in their right hand, they sat down, tilted the bucket and filled it with water from the lake. The water texture in the bucket would be enabled as soon as the bucket touched the lake, without the natural movement. However, all the participants, except for one, collected water in this immersive manner.
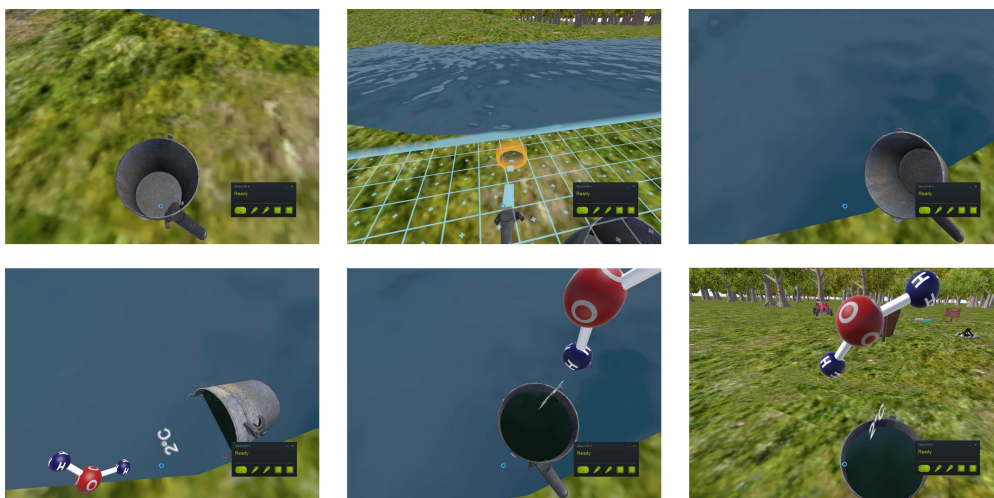
Figure 5.6: The participant picks up the bucket, teleports to the lake,
bends down and collects water in the bucket

Another observation was that several participants tried to turn the pages in the professor's book to find more information. The facilitators informed the participants that the book is static and the pages cannot be turned. For future work, the book will have pages that can be turned.

Furthermore, when the participants added gasoline to the campfire, which triggered an animation and an audio clip of an explosion, several of the participants flinched, took a step back or jumped. In the questionnaire sheet before the VR experience, the students were asked how the gasoline molecule C_8H_{18} looked like. All the students answered incorrect. During the VR experience none of the students picked up the gasoline molecule. Moreover, only 50% of the students read the sign with information about gasoline where the C_8H_{18} formula was displayed. After the discussions with the teacher the students received a second questionnaire sheet were the same question about how the C_8H_{18} molecule was built up. All the students answered incorrect once again. Hence, it can be claimed that due to the immersion and wow-factor the participants did not read the gasoline sign or study the molecule.

Consequently, since the students were immersed in the VRBS they experienced the wow-factor. The wow-factor was enhanced in regards to the possibilities that VR technology supports. For example, some participants picked up the molecules and played around with them, which cannot be done in real life.

A sign was added with information on how to use the HTC Vive controllers, which supported the participants in understanding how to use the controllers. The participants were positioned, at the start of the VR experience, in order to look directly at the sign, which explains

the buttons on the controllers. Nevertheless, after they were placed at this spot, some of the participants turned around. When the participants turned around, they did not notice the sign. One of the facilitators had to notify them to turn around once more in order to see the sign. Nonetheless, as seen in Figure 5.8 only 63% of the participants studied the controller sign. Hence, the immersion and the wow-factor could be a disruption of the VR experience. However, it may have been prevented if the participants had been told that they were placed in front of the controllers' explanation sign.

Figure 5.7: The controller sign displaying information about the controllers' functions
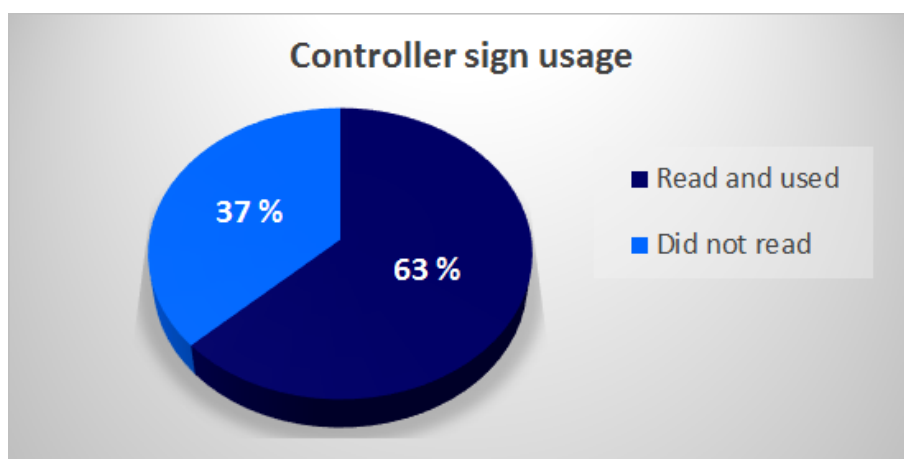

Figure 5.8: 63% of the students studied the controller sign

During the user tests, several participants laughed and smiled in the VR experience when exploring the scene and manipulating objects. In addition, some participants flinched and laughed during the explosion. Quotes such as "cool" and "awesome" was repeated, and some

participants wanted to continue the VR experience even when all of the experiments were solved. Furthermore, one participant talked to the professor and various objects throughout the entire session. In the questionnaire, after the discussion with the teacher, the students were asked if they had fun while using the VR system, where 100% of the participants answered yes.

The students were asked on a scale from one to five, where one was not motivated and five was very motivated, how motivated are they in regards to learning chemistry with the use of VR. The results from Figure 5.9 shows that in overall the students are highly motivated for learning chemistry with the use of VR.
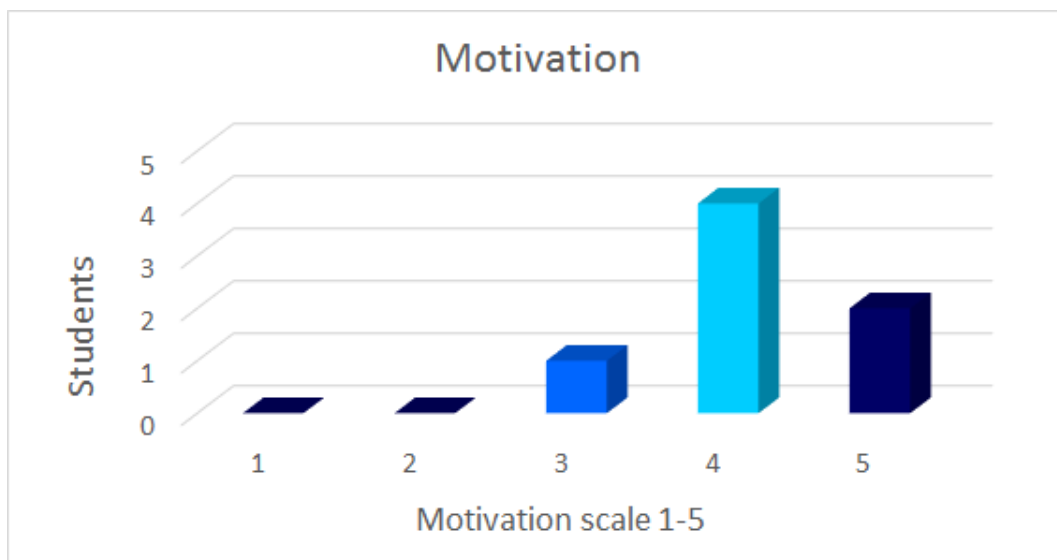

Figure 5.9: The overall students were motivation in learning chemistry with the use of VR

The students were also asked on a scale from one to ten, where one is not likely and ten is very likely, how likely they were to recommend the system to others. The results in Figure 5.10 shows that all the students were likely to recommend the VR system.
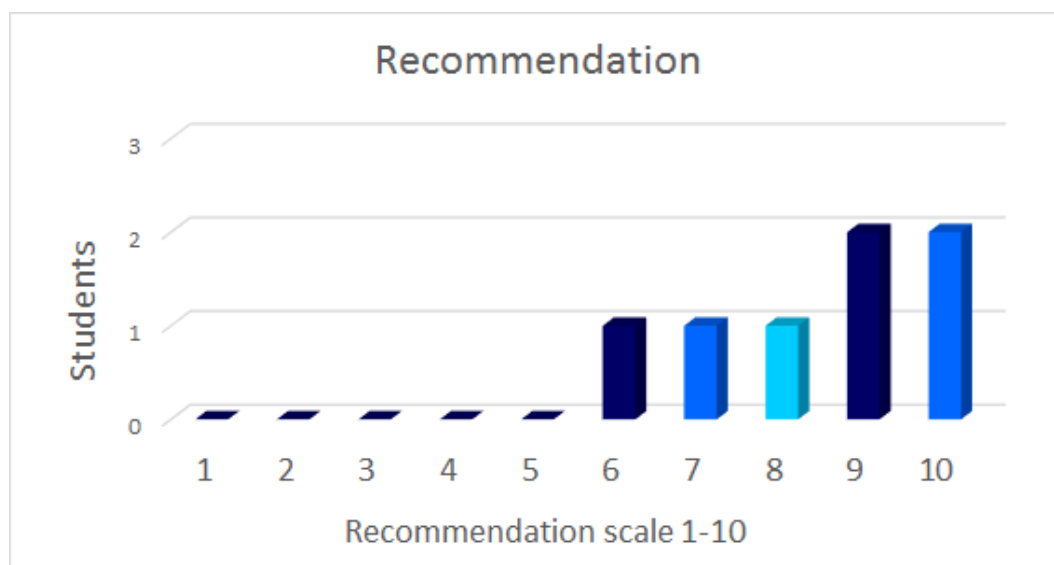
Figure 5.10: The students answered that they were likely to recommend the VR system

Moreover, the students were asked what other experiments they would like to do in VR. The students answered they would like to do experiments regarding pollution, explosives and nuclear bombs.

All of the participants were able to explore the VR scene and manipulate objects. Thus, the participants performed many tasks and gained experience with the use of PBL, SCL and concrete experience from Kolbs Experiential Learning Cycle. The participants were engaged and motivated in their own flow zone with ZPD and fun elements to experience. Moreover, in regards to the hypothesis that virtual reality increases students' engagement through practical experiments, that this research has successfully increased students' engagement by performing the tasks in the VR environment. Hence the goals for concrete experience and engagement are successful.

5.2 Learning in the VR environment

Three participants tried to solve the tasks by combining the actual molecules and the atom. Experiment 2 told the participant to create a small gas cloud with N and H_2O. Some participants tried to solve task # 2 by combining the N atom with the H_2O molecule. In addition, the participants picked up some of the molecules and studied them. Hence, the visual and kinesthetic learning styles were supported.

Figure 5.11: The participant combines the N atom with the H_2O molecule

All the participants tried to do every task on their own and experimented by, in example placing molecules together or placing the gasoline can on the disposable grill. Hence, they observed what happened and if they succeeded in performing the tasks by doing so. Thereby, they used 21st Century skills like e.g. problem solving and critical thinking. When nothing happened, they reflected over the experience by saying for example "hmm that did not work". The hint for the current task would then appear in the book and they could perform the tasks by using the hint from the book and/or from the professor. Another participant read on the Nitrogen sign, in order to give an answer to the professor's question. As seen in Figure 5.12 50% of the participants read the signs in the VR environment. Hence, half of the participants received additional information from the signs. The signs and hints supported the visual, aural and read/write learning styles.
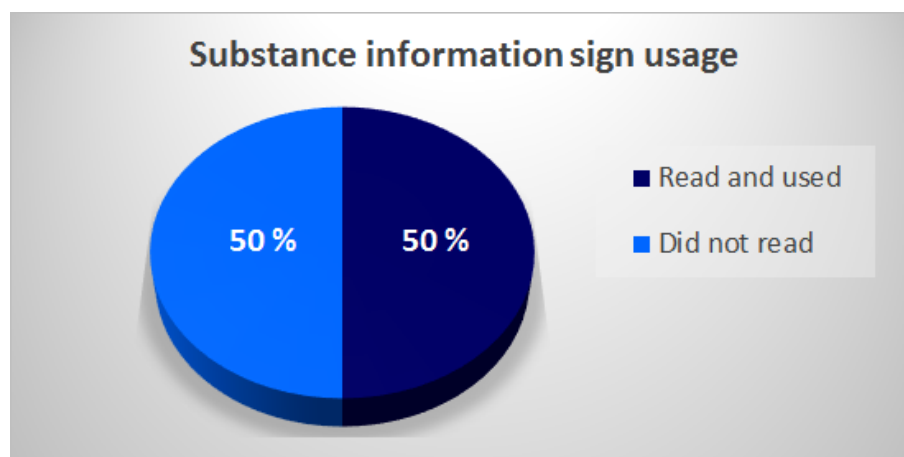

Figure 5.12: 50% of the participants read the signs with information about the various substances

A participant tried to cool the boiling water in the bucket, by placing it in the container that had liquid nitrogen in order to perform task no. 2. Another participant reflected over the difference between a small and large gas cloud. Hence, understanding that task 2 had not been performed. All the participants answered out loud when the professor asked them questions. During the discussions with a teacher, all the students answered and gave comments, some more than others. Thus, the students observed and reflected over the chemical reaction that happened for each experiment.

One of the questions from the questionnaire sheet after the VR experience asked the students if they had learned anything about chemistry from the VR system. One student answered "yes, about what happened in the 4th experiment". Another student said "yes, there is a larger reaction if you have a larger variation between temperatures". The third student said "yes, one thing". The next student said "yes", and the last student said "some". Hence, all the students expressed that they had learned something from the VR experience. Consequently, the question made the students reflect over their entire VR experience.

The participants wished they could receive more information about chemistry during the VR experience. In addition to receiving feedback if they were right or wrong when answering the questions that the professor asked them. Furthermore, the participants expressed that the discussions after the VR experience was a nice way of receiving more information in regards to the experiments. Every participant liked the VR experience and wanted to have a similar VR solution at their school. The responses from the questionnaires demonstrate that the participants had a pleasant experience when using the VR system.

In order to determine if the students read the nitrogen sign, one of the questions in the questionnaire was a closed question about the temperature for liquid nitrogen. The options were -108°C., -154°C and -195°C. The correct answer is -195°C[23]. The results from the questionnaire sheet before the VR experience showed that 20% of the participants answered -108°C, 40% answered -154°C and 40% answered -195°C. During one of the discussions between the teacher and the participants, the teacher told the participants that liquid Nitrogen has a temperature of -178°C. When the students responded to the questionnaire after the discussions, 40% answered -108°C, 20% answered -154°C and 40% answered -195°C. These results might have been different if there had been a better communication between the facilitators and the teacher regarding the questions.

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[23] Encyclopedia: http://www.encyclopedia.com/science-and-technology/chemistry/compounds-and-elements/nitrogen
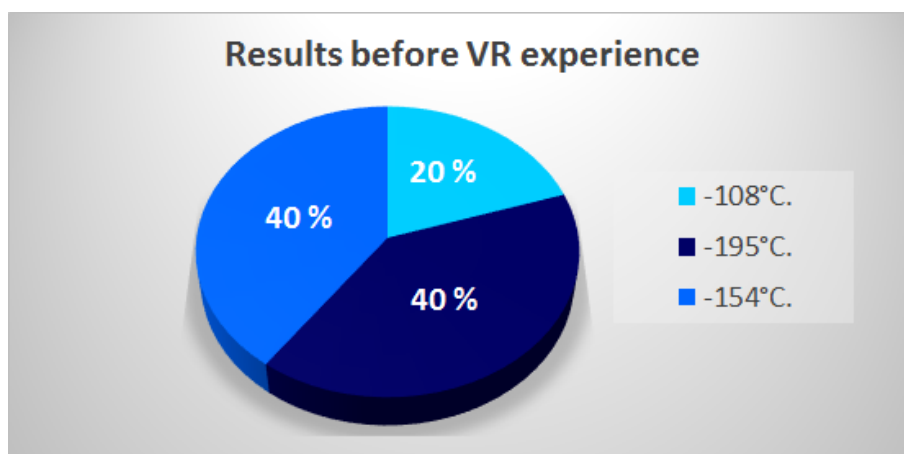
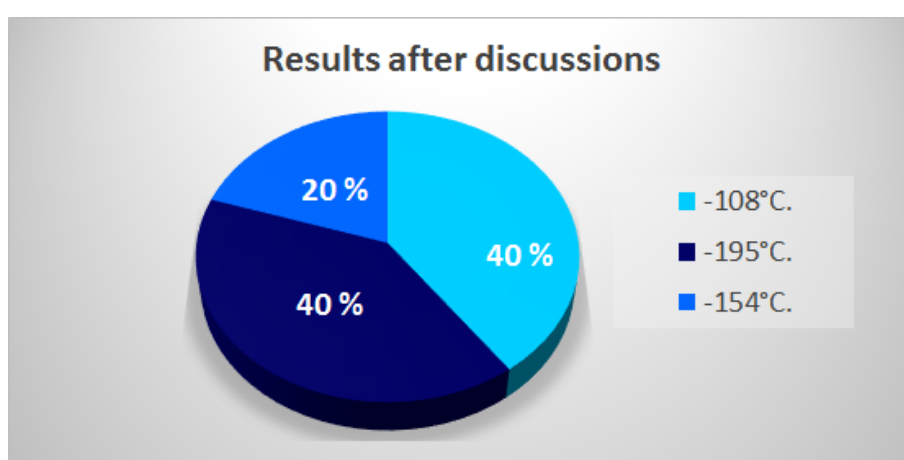*Figure 5.13: 20% of the students answered -108°C.*

Figure 5.14: 40% of the students answered -108°C.

Elements such as signs, hints and audio from the professor supported the VARK learning styles, which assisted the students in completing tasks. When completing the tasks, the students could observe and reflect over the chemical reaction. From the students' observations and reflections during the VR experience, discussions with the teacher and answering the questionnaire sheet after the teacher discussions, it can be claimed that reflective observation from Kolb's experiential learning cycle have occurred. Accordingly, the goal for observing and reflecting is successful. In addition, the science teacher who assisted during the testing of the learning experience concluded that the use of a VR based solution in science education has a major potential as an additional teaching tool. A quote translated to English from the science teacher: "*Consequently suggesting that UiA follows up the pioneer work that the facilitators behind this VR experience has created*". From the teachers view, this teaching tool can be developed to become a very good contribution for the work of science in schools and at Vitensenteret Arendal. See Appendix J for further reading.

5.3   Main Contributions

This research has investigated the possibilities of using VR based solutions to teach and learn chemistry at junior high-school level. The work involved understanding the needs and requirements of teachers as well as students to implement/achieve experiential learning of chemistry bonding. Throughout the work several research questions have been identified and addressed.

RQ1: How to design a VR based solution that enable students to create concrete experience in learning chemistry?

- The VR solution was designed and developed with graphic software, 3D modeling software, a developer tool and a game engine. With the use of the HCD process the VRBS was created, allowing the users to perform chemical experiments and manipulate objects. Hence, concrete experience occurs with PBL and SCL.

RQ2: How can the students be supported in observing and reflecting upon chemical reactions through the use of VR?

- The users performed chemical experiments by manipulating objects in the VR system. When objects are combined a chemical reaction occurs. The students observed the reactions and were asked to explain why the reaction happened. The students reflected over the observation when explaining the chemical reaction. Moreover, during discussions and questionnaire sheets additional reflections followed.

RQ3: What is the effect/impact of active experimentation with VR on abstract conceptualization of chemistry concepts.

- During the VR experience the users expressed enjoyment and engagement. Every user laughed and smiled when they performed the tasks. Additionally, the users were immersed in the VR environment by completing tasks, as they would have in real life. With active experimentation the students played around with molecules and completed tasks. Upon Abstract Conceptualization, the students reflected over the observations by explaining chemical reactions, discussing with a science teacher and when answering the questionnaires. The results from the questionnaires displayed that the users were highly motivated for learning chemistry with the use of VR.

In conclusion, VR make students more active and engaged in the learning through a combination of practical experiments, observations and reflections. Elements that supported the VARK learning styles assisted the students' in creating concrete experience when performing chemical experiments in a VR solution. Therefore, the students were supported in observing and reflecting over the chemical reactions. It can be claimed that integrating a VR solution in a chemistry class, where the students can experience various tasks and chemical substances, could be the beginning of a paradigm shift.

6   CONCLUSION

A VR Based Solution was designed with Unity with the SteamVR plugin, Microsoft Visual Studio 2010, Autodesk 3D Studio Max 2014, Adobe Flash CS 5.5 and Adobe Photoshop CS 5.5. The VRBS allows junior-high school students to do chemical experiments in VR in regards to the lectures in the chemistry class. The students in the research were asked to complete the experiments and explain the following chemical reactions. The students were immersed in the VRBS since they behaved as they would have in the real-world. For example, the students flinched and some laughed when the explosion occurred. Upon completion of all the experiments in the VRBS, some of the students expressed that they wanted to do more experiments or continue exploring the scene. The results from the observations and recordings found that the students had fun while doing chemical tasks in VR. Furthermore, they were engaged and active when using the VRBS and while discussing with the teacher afterwards. During the discussions, the students were asked to explain how the chemical experiments in the VRBS were solved. Hence, reflecting over the experience a second time. In addition, the students expressed that they wanted an explanation on the chemical reactions they had encountered in the VR experience. The results from the questionnaires found that the students were motivated to learn more about chemistry with the use of VR.

Around 95% of the participants had never experienced VR before. When the users put on the HMD, they were amazed by the experience and the possibilities. Hence, they encountered the wow-factor. This resulted in some of the participants being too amazed by the technology to listen to the professor or read the signs about specific substances. Thus, the wow-factor had a disruptive influence on some of the participants' experience.

In regards to these findings, it can be stated that the hypothesis is true. Virtual Reality supports experiential learning and increases students' engagement and active learning through a combination of practical experiments, perception and reflection. Future work is proposed when VR technology is more common and the wow-factor possibly has been diminished. It might be feasible to investigate if the VR experience could support the learning outcomes in chemistry for junior high-schools. In addition, it can be claimed that supporting students in doing tasks with VR technology in a chemistry class could be the beginning of a paradigm shift.

6.1 Future Work

A tutorial should be added in the beginning of the VRBS. The tutorial will allow the users to get familiar with the controllers as well as learn how to pick up, put down and throw objects, and how to teleport in the scene. In addition, they should perform a test experiment, which allows them to explore the scene and initiate signs and audio clips with information. The professor will stand next to the sign with information about the controllers. He will explain how to teleport and how to manipulate objects. The user will be asked to explore the scene, to touch objects and see what happens. In the meantime, the professor will do an experiment in the tent, which will trigger the user's first experiment. Furthermore, a cut scene for the backstory should be added, which can be skipped.

When the user answers the professor in regards to the chemical reaction, the system should register what the user says. The system should analyze the answer and return feedback to the user informing if it is correct.

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APPENDIX A - NSD APPROVAL

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