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VRChemist: Virtual Reality for High School Chemistry

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Preface

This master thesis was conducted in Applied Computer Science at NTNU Gjøvik, and was performed during the spring semester of 2018. This project was first created in a joint subject with Interaction Design, and its design was heavily influenced by this cooperation. After completing this subject, the author felt like the game had potential as a master thesis, and thus continued working on it. Despite some setbacks after the regular 3D version of the game that most of the newer version and bug fixes had been made in did not work as intended in Virtual Reality, a playable and understandable early version was completed by the time testing began. This thesis endeavours to be understandable for laymen, and require only basic knowledge of computers, games and Virtual Reality.

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Acknowledgment

I would like to thank Nannestad videregående skole and Nome videregående skole for helping and participating in the testing phase of this paper, as well as all students and staff who participated. I would also like to thank my supervisor Rune Hjelsvold for guiding and helping me throughout this thesis, and my secondary supervisor Simon McCallum for helping me in the early development of the game. I would also like to thank all master students in Applied Computer Science and Interaction Design who helped me create the game and write the thesis throughout the process.

P. S.

Abstract

As Virtual Reality becomes evermore popular, research is needed to find areas this new technology can be used for. As regular computer games have already been tested for educational purposes, some successfully, it is natural to continue this trend in Virtual Reality. As games and Virtual Reality separately provide increased visualisation, together they may greatly improve this for school subjects where this is needed. VRChemist is a Virtual Reality game designed primarily for high school students, and visualises atoms and molecules in a brand new way. VRChemist was tested on 7 teachers and 17 students from two Norwegian high schools to see if students and staff alike agreed that this added visual representation may be of great aid to supplement traditional learning methods in high school to improve the understanding and motivation in the subject. The results were positive, with no nausea or dizziness felt by any participant, no significant differences between the different ages or genders of students, and high interest in what a full version of VRChemist and any other potential software for Virtual Reality.

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1 Introduction

The idea of using games for educational benefits has been around for decades now[1], and as the video game industry progresses, more and more students become adept at playing games at an early age. Bonde et. al. at the Technical University of Denmark[2], for example, conducted a test where they reported a 76% increase in student learning outcomes when using a gamified laboratory simulation called Labster alone, and a 101% increase when paired with traditional learning methods. As the gaming industry leads the charge in Virtual Reality technology, the ability to use this technology to improve student learning and/or interest also cross over to using Virtual Reality games for educational benefits. Labster[3] is already using Virtual Reality through a number of universities and seeks to expand this further. Moxnes and Ristesund at the University of Agder[4] tested a self made game to teach secondary schools students chemistry where they had positive results from the students who tested their application.

VRChemist builds on some of these experiences, and seeks to visualise molecular chemistry on a high school (15-18) level. This game allows players to pick up atoms and bindings in a Virtual Reality using the HTC Vive and attach them to eachother to form molecules. The atoms themselves are presented as spheres and the bindings as sticks, to provide simplicity and easy understanding to the game as well as conform to the models thought in Norwegian schools. The testing performed in this paper is based on an early prototype version of the game, limiting the amount of exploration students can commit to, but is sufficient to provide an overview of what is possible with both the game itself and the technology. This paper endeavours to uncover feelings that both students and staff alike hold for this game as well as the potential future of Virtual Reality in classrooms as a whole.

Terminology

- Virtual Reality - "Virtual reality (VR) is a computer-generated scenario that simulates experience through senses and perception. The immersive environment can be similar to the real world or it can be fantastical, creating an experience not possible in ordinary physical reality."[5]
- HMD - Head-Mounted-Display. A piece of high-tech equipment used to project images directly in front of the user to provide a Virtual Reality experience.

1.1 Hypothesis

Does Virtual Reality hold the potential to replace or supplement traditional learning methods of visual representation of the curriculum in high school? This paper hopes to show that Virtual Reality does indeed have the potential to improve either student understanding or student interest in subjects that rely heavily on visual representation through the use of models. The null-hypothesis for this is a rejection from either staff or students on either finding the game and idea presented to them as interesting or with learning potential. This is because a rejection from staff may hinder the adaptation of the use of this new technology in schools to such an extent that it may become too expensive to use time and resources to re-convince staff members of this. A rejection from students may render the idea pointless, at least for the current generation of students. A rejection of interest may lead to only replacing one boring lecture with another, preventing any bonus of increasing student motivation in the subject. A rejection of the learning potential of Virtual Reality would make the system too expensive for schools to invest in for the sole sake of increasing student interest.

Secondary research questions include:

- Is there a disparity between male and female students? A too great disparity between the genders at a young age could increase overall differences of school experiences between them.
- Is there a difference between student ages? If younger students find the game more interesting than older students or Vice Versa, the game or technology may be too simple or complex for one group or the other.
- How many become nauseous or dizzy from using Virtual Reality? If this number is 0, some lessons may be learned from how Virtual Reality was used in this context and would require further research. If the number is low, then this would be considered normal and acceptable. High numbers of nauseous or dizzy would suggest a problem with the game.

1.2 Related Work

Biotech Learning in Denmark and the USA

Labster[3] is a gamified laboratory simulator designed to teach students chemistry on a high school level. Bonde et. al.[2] at the Technical University of Denmark researched the effect this game would have on high school and university students. 41 students from Stanford University Online High School first took part in an experiment regarding the genetic engineering lab, where 40 students reported the simulation to be "interesting and relevant subject matter" and 23 students reported it was "more motivating than classroom or home wet labs". 149 students from

Archbishop Williams High School and the Technical University of Denmark tested the crime scene lab simulation, and reported that 97% "found it interesting to use the simulation; 86% indicated that the laboratory simulation was more interesting compared with ordinary exercises; and 97% felt that the course content was more interesting when working with gamified simulations". An additional 87% "indicated that they learned something by using the gamified simulation". A further 57 students from multiple danish high schools were tested, and 44% agreed to a statement saying "I consider pursuing an education within biotechnology or other biological subject to a greater extent, after having used the gamified laboratory simulator". The team therefore concludes that gamified simulators increase both student motivation and learning outcome "when compared with, and particularly when combined with, traditional teaching."

Computer Science in Greece

Papastergiou's research paper [6] conducted in Thessaly, Greece, aims to find if a gaming application is better at teaching students cognitive skills in Computer Science than a non-gaming application. In her study, 46 students tested the gaming version, while 42 students tested the non-gaming version, while not including a control group to use traditional learning methods. The game itself is centred around puzzle solving in a maze-like structure, where the students must answer questions correctly in order to move towards the exit on each level. The non-gaming application is a standard web-based interactive learning tool, where students first read about the topics presented, then answer a simple quiz to enhance their learning.

The results of these tests indicated that both the average grades and the general interest increased significantly for the students who played the game over those who used the non-gaming version. Furthermore, boys showed a higher level of interest for the game than the girls did, indicating some gender bias towards the gaming solution. The author also points out in her conclusion that she did not include traditional learning methods in the tests, and that the tests were conducted only short-term, and that further, long-term studies should be done before any definitive conclusion can be made.

Genetics in the USA

In Annetta et al.'s paper [7], the authors attempt a more systematic approach to researching the effectiveness of games in modern education. In their study, they take an unnamed MEGA, a Multiplayer Educational Gaming Application [8], which was created by a teacher and analyse the students' learning and engagement. The game itself was "designed and built to probe student understandings of pedigrees, Mendelian inheritance, blood types, and DNA fingerprinting through a problem-based crime scene investigative mystery". The game had a minor story based on a crime that the students had to investigate the source of using genetics clues left behind by the victims and the murderer. This game was tested on a total of 66 students, with an additional 63 students used as a control group, in North Carolina, USA.

After carefully reviewing the results of their experiments, the researchers rejected their main initial hypothesis that the game would increase the students grades, as they could find no significant improvement over the control groups. However, the level of interest in the test subjects, especially among the boys, was significantly higher. The authors thereby conclude that, "although disappointing to some degree, should not undermine the use of this emerging technology. Rather, it helps reinforce the critical need for further research aimed at isolating and documenting the cognitive impact of this technology. [...] if new and innovative technologies (such as educational games) are more engaging and appealing to students [...] then this in itself may justify the use of and deeper investigation of these new technologies."

Augmented Reality Chemistry in Norway

The Table Mystery [9] is a game created by Boletsis and McCallum for the Science Centre in Oppland, Norway for the purpose of teaching children chemistry. In the game, the player must help a man recover from his amnesia by solving chemistry related puzzles through Augmented Reality. It was only tested on 6 adult experts, with more tests to be done before a full release. The experts were impressed with the possibilities of Augmented Reality, but expressed some concerns related to the difficulty of some of the puzzles, which the authors stated they would look further into. While expanding upon the students' knowledge was not their main concern, they stated this will also be tested before a full release. It is mainly designed to increase the students' interest in science and learning, as is the general purpose of science centres, and in their preliminary experiments, this goal seemed achievable.

Non-HMD Virtual Reality Geography in Greece

VR-Engage is a multi-use game and simulator used for anything from gaming to training and studying. In Virvou and Katsionis' study [10], the game was adapted to teach students geography in a 3D environment of a Doom-like adventure game. In the game, the player moves around the level and solves puzzles and fight monsters. Any puzzle that shows up relates to geography, in theory forcing the students to learn as they play. It was tested on a total of 50 students of varying experience with video games in the past in Piraeus, Greece.

The game was well received by some compared to standard education. Novice gamers had a hard time understanding what to do and how to navigate. Experienced gamers found the simplistic graphics and gameplay to be boring compared to more modern commercial games and refused to play it outside of school, but still preferred it to regular classes. Virvou and Katsionis therefore concluded that both a better, more adaptable tutorial for novice gamers and more interesting gameplay and graphics for experienced gamers could solved these problems, and would like to see more studies addressing these issues completed in the future.

2 Method

2.1 Implementation

VRChemist was created as a simulator tool for educational purposes in Virtual Reality with the possibility of expansion to a game for education. The framework is based on the "HTC Vive Tutorial for Unity"[11] from raywenderlich.com, with the only game objects left identical to the tutorial being a table in the middle of the room and one type of box, and with all code modified to some extent. The table was kept to have both a point of reference in the room as well as a place to keep all atoms and bindings until another place to gather up these could be made. The boxes were kept with their original mechanics and textures as an introduction to Virtual Reality for new players, as they could use these to find the differences between Virtual Reality and real life as well as get used to the controls, with particular focus on the grabbing mechanics, as early testing showed this was the most confusing part for new players. The boxes later turned out to be a student and staff favourite, as they could build use them similarly as to how they would use real life blocks, but without repercussions.

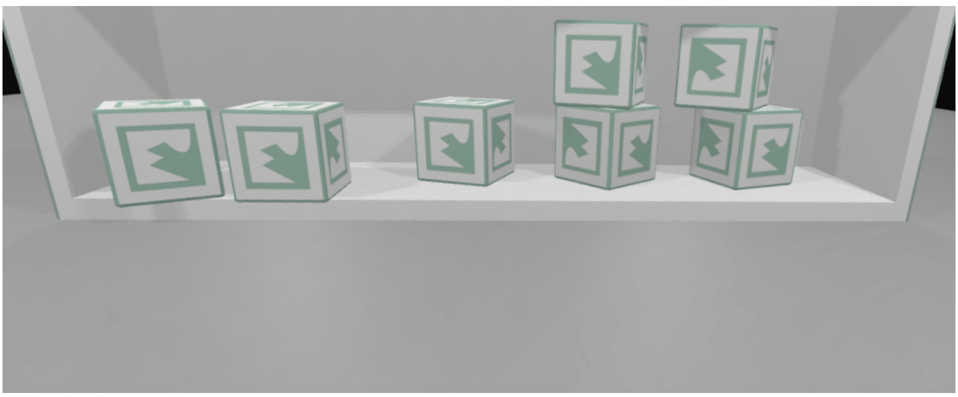

Figure 1: Table and boxes with regular physics

The atoms in the game are simple coloured spheres. Each atom type was given a unique size and colour to make distinctions between them easier, with colours attempted to match what colours are usually used to represent what atom in Norwegian high school chemistry sets. This meant the colours red for Oxygen (O), black for Carbon (C), and white for Hydrogen. The sizes were designed to represent their atomic value in the periodic table, with Oxygen (8) being the largest, and Hydrogen (1) being the smallest. Their actual in game sizes are arbitrary, with future work (see 5.1) planned to make their sizes entirely dependant on their atomic values. Due to lingering confusion when represented with these atoms as to which atom was meant to be which, free floating text was added in front of each of their starting positions. This text uses the Norwegian translations of each atom, as localisation for International use was not intended for this project.

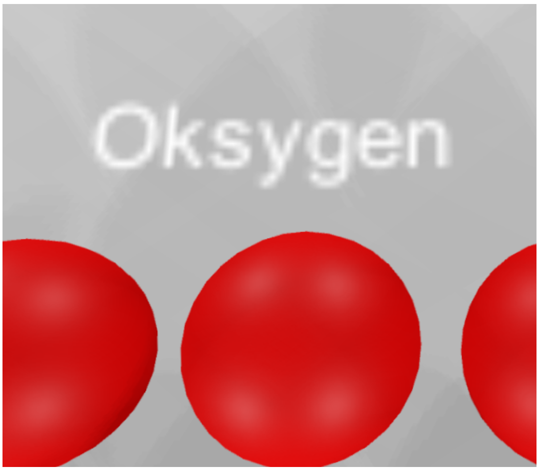

Figure 2: Oxygen atoms

Figure 3: Carbon atoms

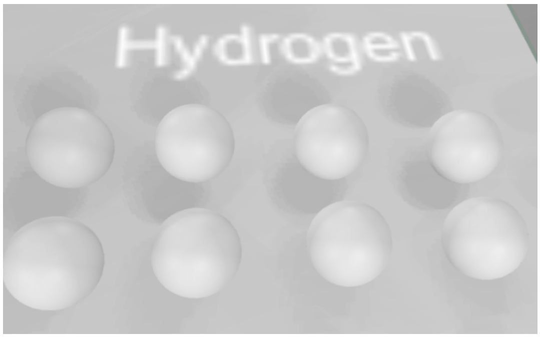

Figure 4: Hydrogen atoms

The bindings are programmed only to connect to atoms, only to do so on their two ends, and not to connect to anything if there is already a connection there. These simple rules make it robust against attempts from players to attach it to multiple objects or the tutorial boxes, but creates the three main bugs that players encounter when playing the game. The first bug is caused by the ability to attach the binding to anywhere on the atom. While this creates a freedom of construction for the players which occasionally increased the entertainment brought by the game to players during testing, it causes a problem when attempting to play the game seriously. The player often need to detach the binding, which is done by simply grabbing the atom with one hand and the binding in the other and pulling them apart, and then reattach them to make them look "nicer". The second bug is simply that when the binding and the atom are attach, they leave behind a noticeable gap between them. The third bug occurs when attempting to build a large molecule. If you put an atom in the middle, a binding on the left, right, top and bottom (looking at it from one side), and then attach another atom to each of these bindings, the outlying atoms will try to exert physical movement back to the centre atom, which in turn will cause the centre atom to exert physical movement back to the outlying atoms. After a few seconds, the in-game physical force made by the atoms and bindings on eachother becomes great enough to break the joints that hold them together, something only the player should normally be able to do. This, in effect, creates an explosion as the atoms and bindings scatter in all directions. Unfortunately, this bug cannot be presented in this paper as it supports printing, and animated GIFs do not print well. Luckily, testers found this last bug to be so hilarious that they demanded it to be kept as a feature in future versions of VR-Chemist. This is also the reason for why only Hydrogen, Carbon and Oxygen were chosen at this stage, as few combinations of these creates large molecules.

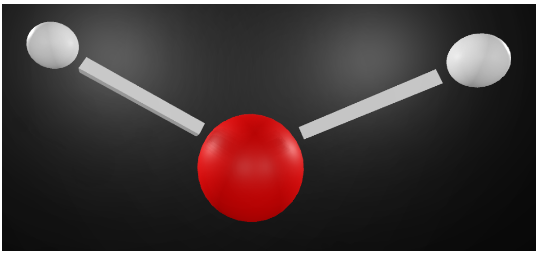

Figure 5: A simple H2O molecule in VRChemist

On the wall on the other side of the table from where the player spawns, a whiteboard with simple objectives has been placed. The player is tasked with creating water (H20), carbon dioxide (CO2) and hydrogen peroxide (H2O2), three simple molecules that can be made from the atoms and bindings provided. The board and its contents is static, and does not record mission completion (see 5.1).

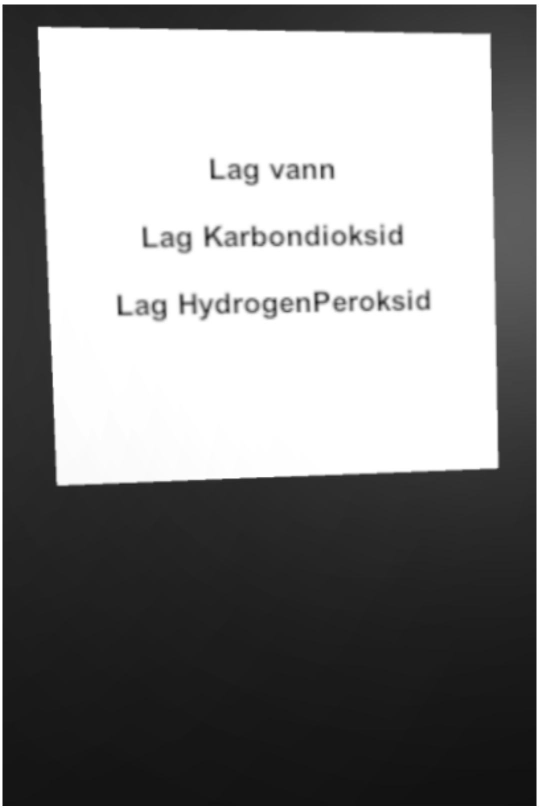

Figure 6: Whiteboard with missions for the player

The room itself has black walls and a black ceiling, paired with a white floor. This is both to avoid fixation of these and to make sure the objects in the room stand out and can be seen clearly. Teleportation is done by pointing the cursor at the ground, holding down the touchpad to see where you will teleport to, and releasing it to teleport there. Clicking and holding down the trigger at the back of the controller grabs an object, on the condition that your virtual controller is inside the object.

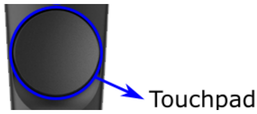

Figure 7: Location of touchpad

Figure 8: Location of trigger

2.2 Testing

A full step-by-step walkthrough of how testing was done can be read in Appendix B. Each participant was asked to sign an information agreement that stipulates what participants will do, and what and how their answers are used in this paper. This agreement can be read in Appendix A. Participants would then be introduced to the controller and shown how to hold the touchpad and trigger, as well as what these did, before entering the game. When inside the game, participants would first be asked to teleport around for a bit to get used to this, before being asked to grab either the boxes underneath to get used to the physics, or to grab the bindings or atoms and start building. After becoming acquainted with the controls, the participants would be asked to look at the whiteboard and follow the instructions there. When these tasks had been completed, the participants were free to play around as much as they wanted within the game until they were bored or a total of 15 minutes had passed since putting on the HMD. This time limit was not always held, as other distractions such as others asking various questions did occur from time to time. A secondary 20 minute time limit was more strictly held for students under 18, but not for staff due to an agreement with NSD (Norwegian

Centre for Research Data). During the course of the testing, the author would note down various observations of events or reactions that are not covered in the survey or interview. After exiting the game, students were asked to participate in a survey, while staff were asked to participate in an interview.

2.2.1 Students

Students were asked to do a survey to allow for easier comparison of a potentially large group. This survey includes the age of the students separated into 15 (the youngest age approved for this testing by NSD), 16, 17, 18, 19, and 20+, to distinguish between potential maturity and school year. The gender of the students was also included, separated into male and female (as it was believed adding other genders may corrupt the results if younger students chose these for fun. University or otherwise adult testing would account for other potential gender identities), to see if any there were any significant gender difference in student interest. Nausea and dizziness account for the third and fourth questions to see if there were any discomfort among the students. The fifth question focused on student difficulty of using the controllers, as it was hoped that the simple control scheme would not become arduous for new players. Sixth was to see if students could describe their experience in this new environment, with some words already presented to them with the option to add their own. The seventh and eight questions ask how entertaining the game itself was and why, as any problems pointed out by the students here may be fixed later. The ninth and tenth questions focus on the difficulty of picking up and attaching objects, as this was a major hurdle during development and it could have been worrisome if the current solution for this did not work as intended. Eleventh and twelfth focus on the design of the atoms, as the distinct colours and sizes of these should distinguish them even in a cluster of different molecules, but testing this was necessary to be sure. Knowledge of students experience in chemistry was also necessary to back up, as it was expected that all students would have knowledge of this due to the Norwegian standard of learning chemistry in the mandatory natural science (naturfag) subject in secondary school (ungdomsskole), but that this claim required confirmation from the students. Finally, the students were asked to compare their recent experience in VRChemist to the traditional learning methods of books and 3D chemistry sets. It is known that this last question may be biased towards the student Virtual Reality experience due to this being much more recent, but it may still be useful to see how the students themselves felt the comparison was like. The full questions can be found alongside the answers in the Results 3.1 section or Appendix C.

2.2.2 Staff

The staff members were given a semi-structured interview as per E. v. Teijlingen [12], as only a few staff members were expected to agree to participate in the testing. Although the main focus staff participants to be acquired would be teachers, other staff members such as IT-personnel, counsellors and principals/ vise-principals were welcome to join, and questions were geared accordingly with a main focus of educational improvement for students, but using questions most could answer. The questions were divided into five segments; VR problems, VR benefits, Game problems, Game benefits and VRChemist. VR problems asked specifically potential student nausea, dizziness, etc. to see if the staff were worried about this as an issue that may hold students back from trying out the game voluntarily, potential communication problems in VR, as this may send the class into chaos if teachers are unable to control the students, and potential injuries, again to see if the staff considers this a problem. VR benefits specifically includes replacing traditional learning methods with VR, to see if staff considers this a plausible future, VR as a visualisation aid, as this is what VRChemist was designed to be, and VR as a long distance communication device for either sick, injured, or otherwise absent students, or students from other schools, as Virtual Reality multiplayer is growing alongside the regular gaming community. Game problems asks about games for education in general, with specific questions for student distractions and a false reality picture, as these two tend to be used in debates against games in general, and potentially creating differences between students, as some students are more adept at video game than others. Game benefits focus on student interest in the subject, to see if the staff believes games can increase this, and teaching more/ better than traditional methods such as books. This last question was added to make the staff wonder about how this can be done, as well as potentially see if they can come up with more benefits for gaming. The VRChemist portion of the questions focus entirely on the game design, to find problems and successes of the game. Each segment (apart from the VRChemist segment) ends with a "Can you think of anything else?" question to solidify the interview as a semi-structured one, providing as many different answers as possible. The full questions as well as their answers can be found in Appendix D.

3 Results

The total number of respondents amount to 17 students for the questionnaire and 5 staff members, all teachers, for the interview. An additional two staff members, also teachers, answered the questionnaire due to miscommunication during testing. These two ca be recognised in the charts and tables for the questionnaire by their registered age being above 22 years old, and will be compared to the staff interviews instead.

3.1 Student Responses

Student responses were collected from 2 Norwegian high schools. Although unconfirmed as the students were not specifically asked to provide this information, all students are part of study specialisation (studiespesialisering) courses or courses with partial or optional study specialisation. This means that most, if not all, students had experience in chemistry from their first year natural science (naturfag) subject.

3.1.1 General Responses

Age

The age of the students are exclusively 17 and 18 years. This shows that the students are all (most likely) second and third year students, and are more likely to have experience with both chemistry or related subjects and technology. The two twenty-year-olds represent the before mentioned teachers.

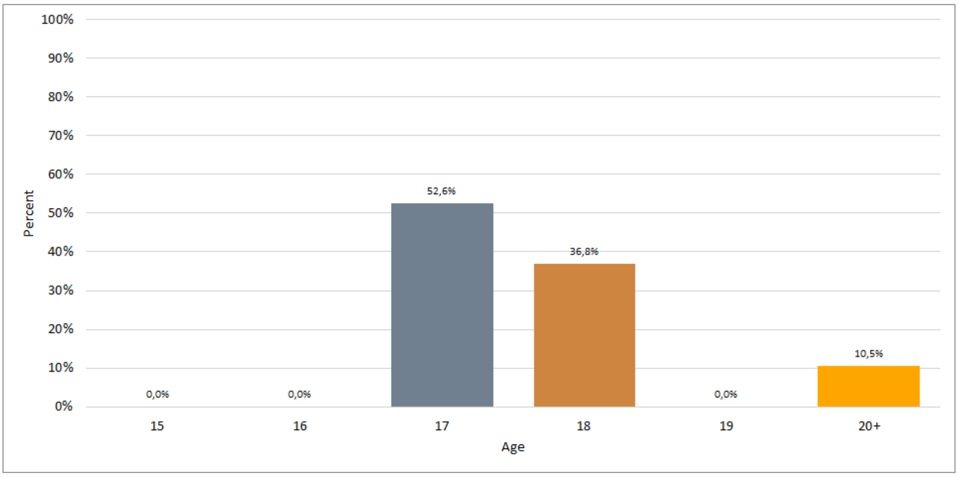

Figure 9: Age of students. N = 19

Gender

The majority of the students tested in this study were female. As the two twenty-year-old's were female, the actual percentage of the two genders are:

- Male: 37
- Female: 63

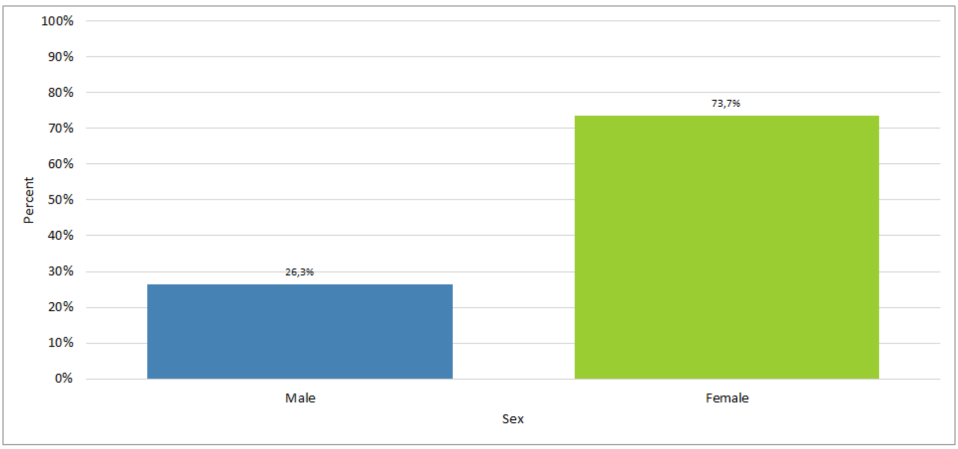

Figure 10: Gender of students

Nausea

Not a single student reported any nausea from using the VR-HMD or playing the game.

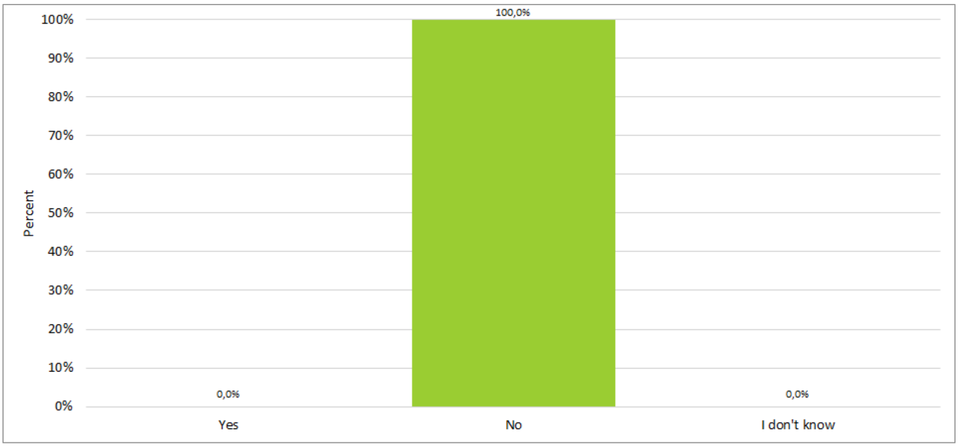

Figure 11: Nausea felt by students

Dizziness

As with nausea, not a single student felt any form of dizziness after using the VR-HMD or playing the game.

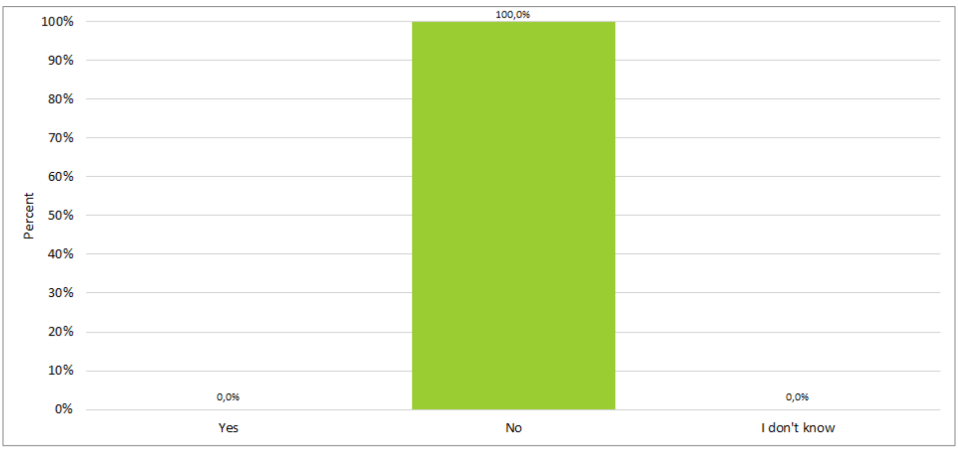

Figure 12: Dizziness felt by students

Using the Controllers

Only a minority of students felt unsure whether or not it was difficult to use the controllers. Most students, however, felt using the controllers was easy, despite not being able to see what they were pressing. Observation during testing confirms this, as the students could get buttons mixed up early on, but quickly adapted and felt where the buttons were on the controllers.

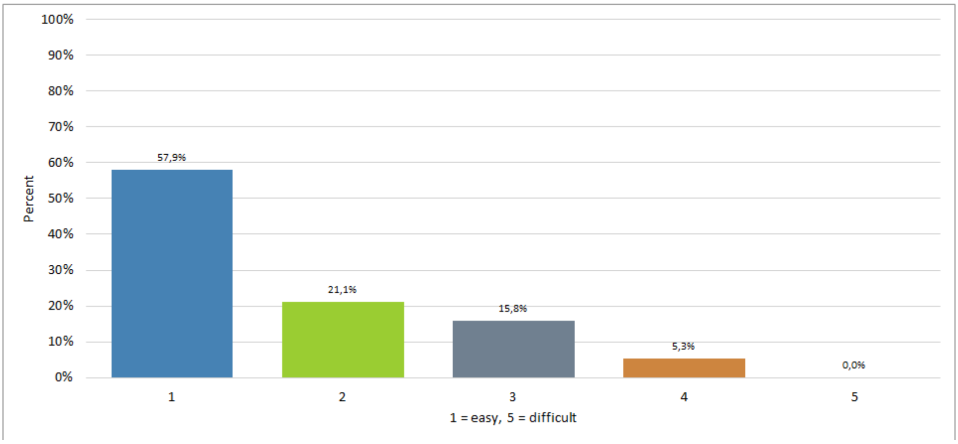

Figure 13: How difficult it was for students to use the controllers without being able to see their own hands

Walking in a Virtual Room

As the majority of students felt walking in a virtual room was funny and/or exciting, it may have been a positive experience for most students. As the majority also felt this was strange, an ambiguous term for these tests, it may also take some time to get used to being in a virtual room before it becomes more "normal", especially as some also felt it was disorienting. The fact that some people felt it was easy may be because some students had experience with Virtual Reality, but as this was not part of the tests, this is unclear.

Figure 14: What students felt when walking in a virtual room

Entertaining Game

The vast majority of students found the game entertaining in the preliminary question.

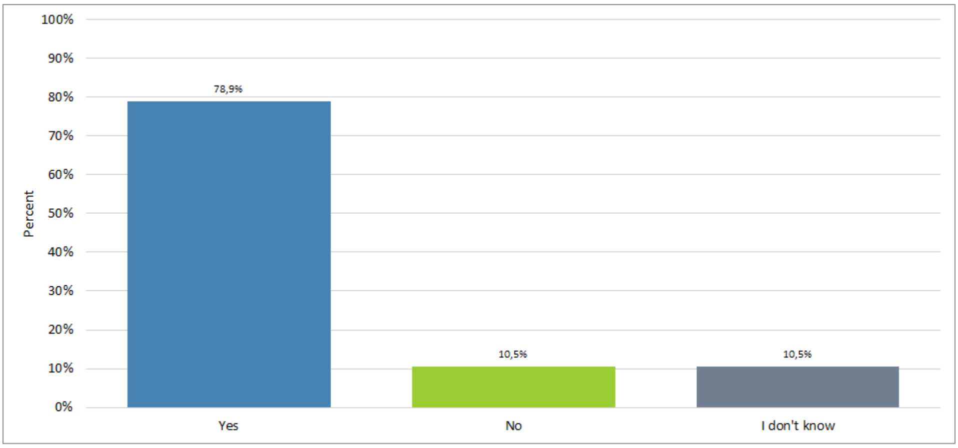

Figure 15: If the students found the game entertaining or not

As this question had a "Why?" part (see C.7.1 for the full translation), their written answers provide some insight to this. The main responses detailed how this was a new experience for them, leaning towards Virtual Reality rather than the game itself, that they could visualise the atoms and build what they want, and that this is a fun way to learn or relearn chemistry, leaning back towards the game itself. The responses surrounding the limitations of the game were expected, but one response that the room was boring to look at may suggest that improving the environment may be necessary. Otherwise, it seems as if many would like to try the game again or have it as a part of their learning experience at school.

Picking up Objects

Students seem more divided when it comes to picking up objects in the game, with near equal numbers of students finding it really easy, doable and somewhat difficult, while the largest group felt it was somewhat easy.

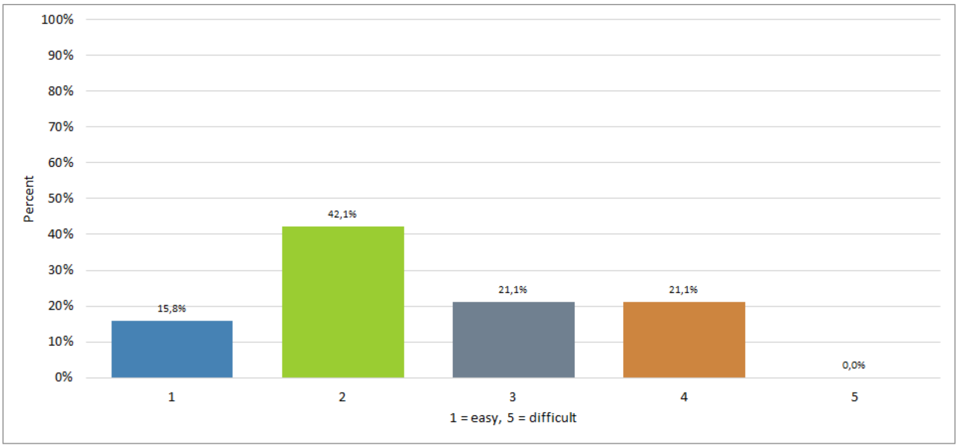

Figure 16: How difficult the students felt picking up and attaching atoms and molecules was

This question also had a "Why?" part (see C.8.1 for the full translation), and some insight can therefore be gained into this division. Those who believed it was easy to pick up objects only found some bugs problematic, such as molecules floating away for apparently no reason. Those who felt it was somewhat difficult seemed to only have problems getting used to the controls and environment in the beginning, but otherwise adapting over time. For those who found it more problematic, it was difficult to find the distance to the objects and grab them or understand how the bindings worked in relation to other objects in the scene. Bug fixing and some rework on the bindings may be necessary to counter this.

Distinguishing Between Objects in the Scene

The majority of students found it easy to distinguish between the objects in the scene, including their own creations.

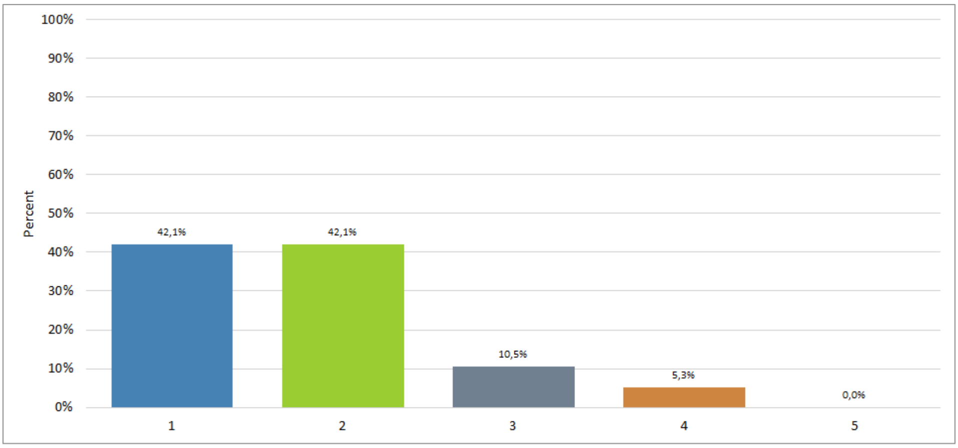

Figure 17: How difficult the students felt distinguishing atoms and molecules was

Again, the "Why?" section (see C.9.1 for the full translation) provides some insight into this. This time the students mostly agreed with eachother, and felt that the text boxes, distinct colours and size differences all improved visualisation greatly. The most relevant extra comment was that the atoms should have had their atomic codes embedded into their shells, an already planned feature for future work.

Chemistry Experience

As expected from a Norwegian high school, all students had previous experience with chemistry.

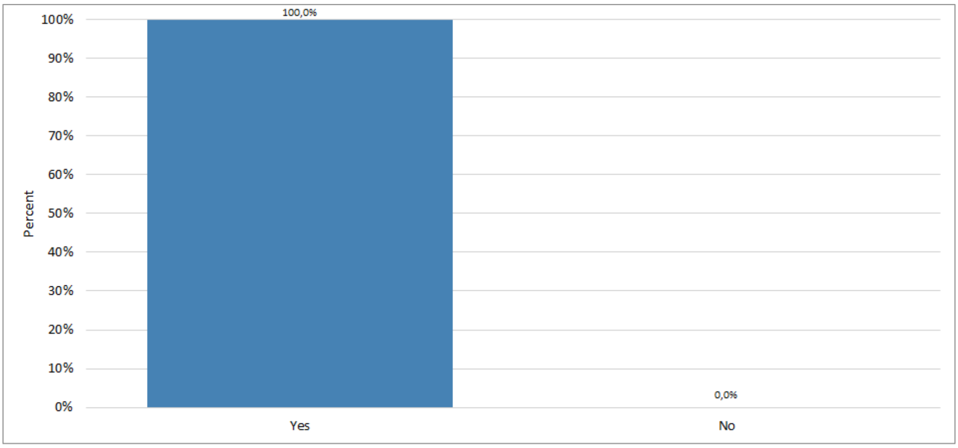

Figure 18: Whether or not students had any experience with chemistry

3D models in Chemistry Experience

The vast majority of students had used 3D models in chemistry before, most likely from chemistry set toys used in either 10th grade secondary school (ungdomsskole) or in high school. The low number of students who responded "no" may suggest some confusion around the question or a different background from the others.

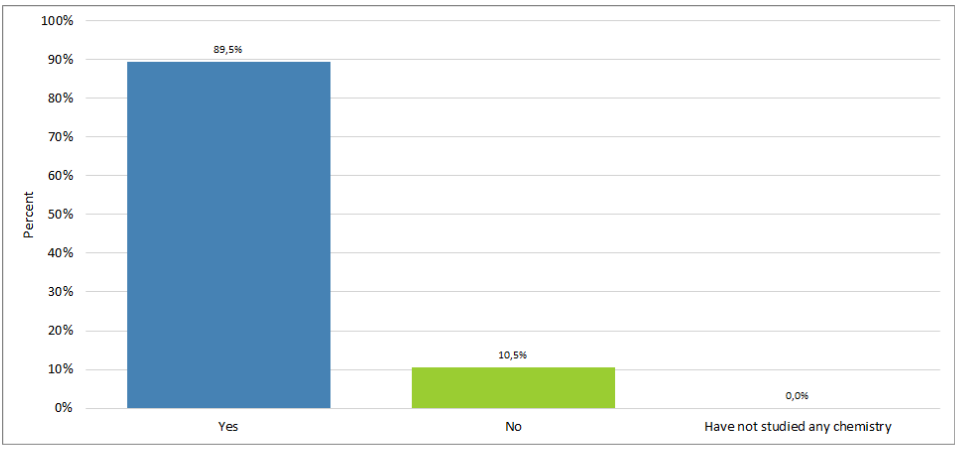

Figure 19: Student experience with 3D models in chemistry

Virtual Reality Compared to Books and Physical Models

As almost every student found Virtual Reality to be more engaging than traditional methods, both the game and Virtual Reality in general may improve student interest in the subject if used more extensively. A slight majority thought this was also more understandable, which may increase the number of students who understands the subject, possibly including grades. Only some found the game and Virtual Reality to be easier and/or more comfortable, which is to be expected from a brand new piece of high tech equipment. Only a few students had anything negative to say in comparison to traditional learning methods.

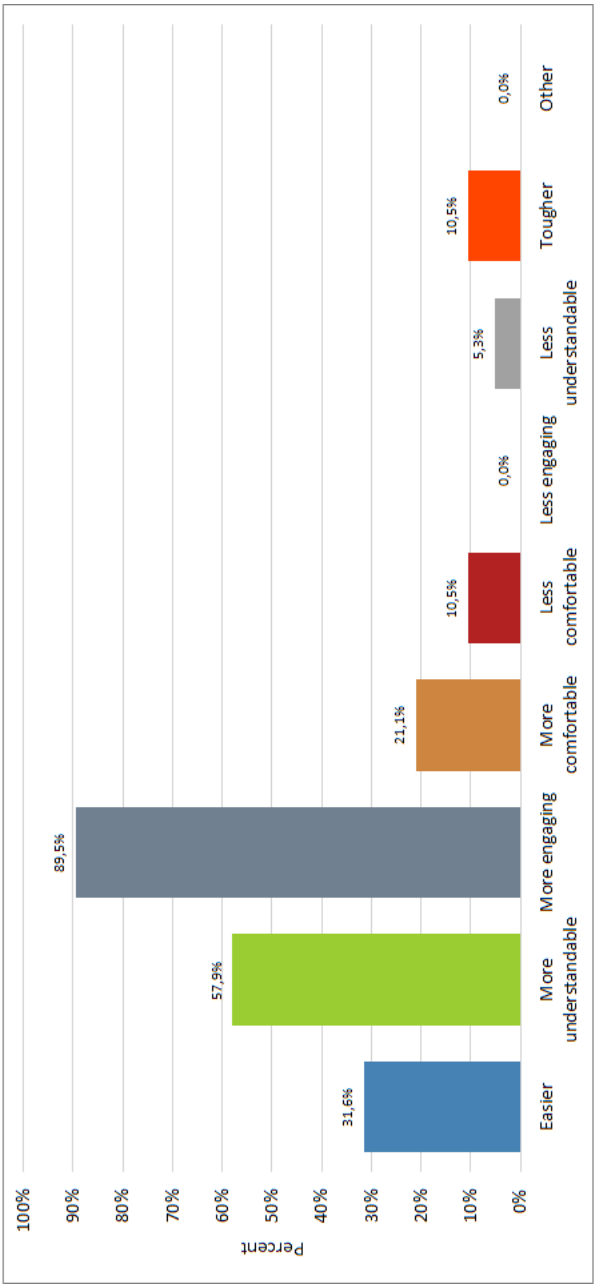

Figure 20: What students felt Virtual Reality was like compared to traditional learning methods

3.1.2 Age Based Responses

This compares the age of the students involved to the questions they were given. This does not include the nausea, dizziness or chemistry experience questions, as all students provided the same response to these. Furthermore, it does not include the "Why?" questions, due to the possibility of using this information to remove the anonymity of students. Two respondents declared they were above the age of 20, which are the teachers who were misplaced during testing, and will be discussed in the staff responses (3.2) instead.

Using the Controllers

The age of the students seem to have no effect on how difficult it was for them to use the controllers without the ability to see their hands.

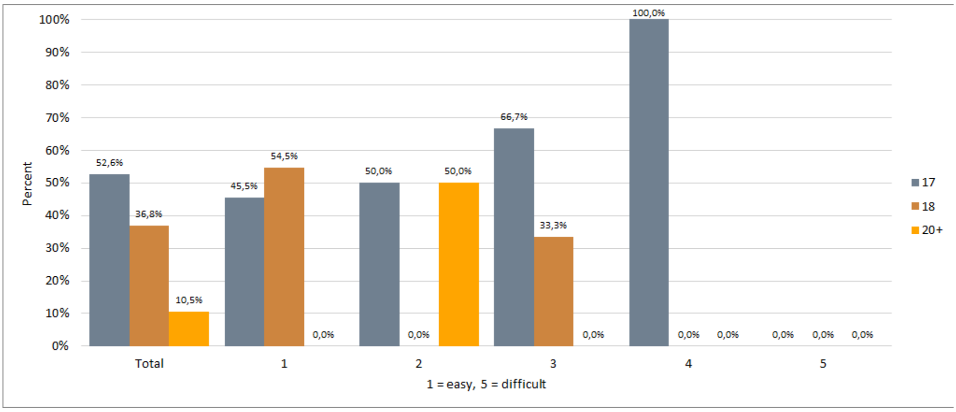

Figure 21: Age distribution of students when using controllers without the ability to see their hands

Walking in a Virtual Room

At first glance it may seem as seventeen-year-olds find the experience of walking in a virtual room to be particularly scary and difficult, but both of these only account for one response each. There are therefore no significant age differences in the experience of walking in a virtual room.

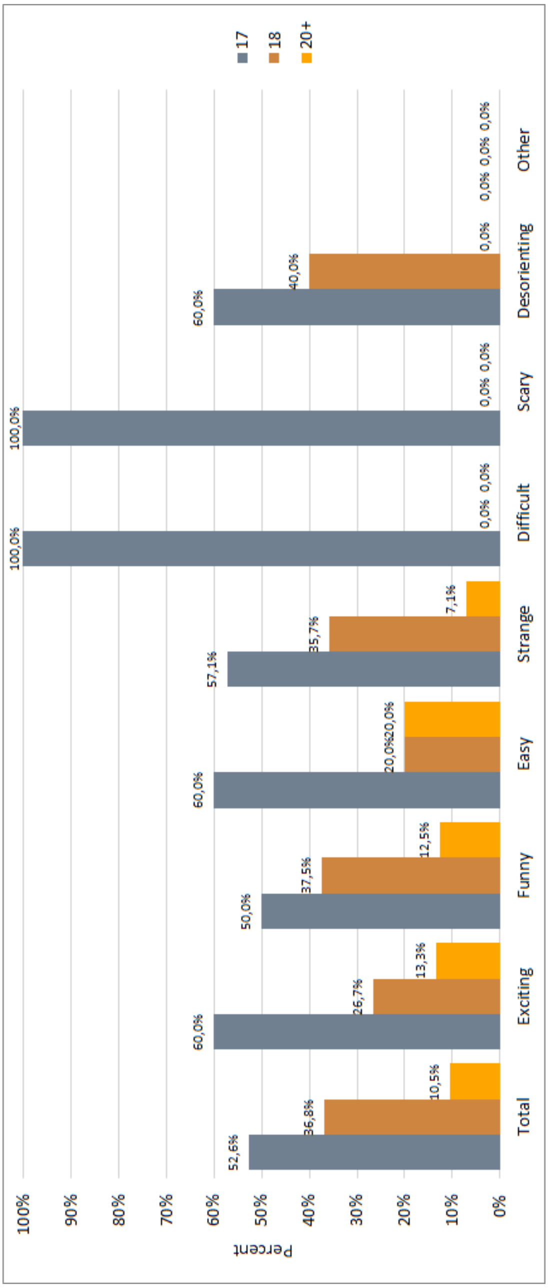

Figure 22: Age distribution of students when walking in a virtual room

Entertaining Game

Here it may seem as eighteen-year-olds are unsure of whether they found the game entertaining or not, but again this only accounts for one student. Age does not cause any significant differences in finding the game entertaining.

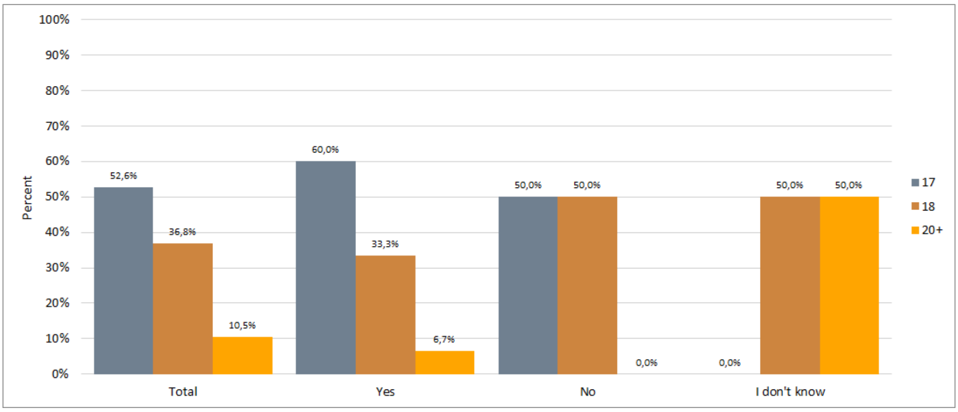

Figure 23: Age distribution of students finding the game entertaining

Picking up Objects

A slight increase in difficulty in picking and attaching up objects is shown for seventeen-year-olds over 18-year-olds. This may be because the older students have become slightly more experienced in their extra year of learning, but is most likely a coincidence.

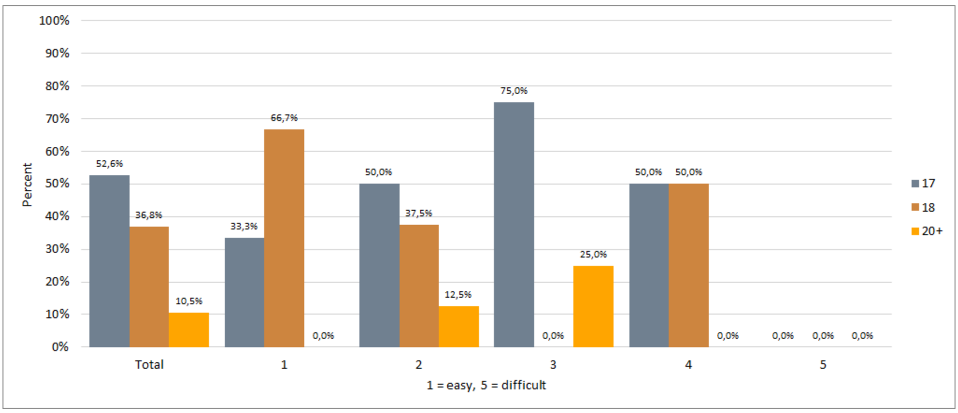

Figure 24: Age distribution of students when picking up and attaching objects

Distinguishing Between Objects in the Scene

Seventeen-year-olds seem to find it slightly more difficult to distinguish between different atoms and molecules in the game, but as they still find this to be easy, this does not have a major impact in age difference. The students who responded with "3" and "4" are single students and have no impact on the age difference.

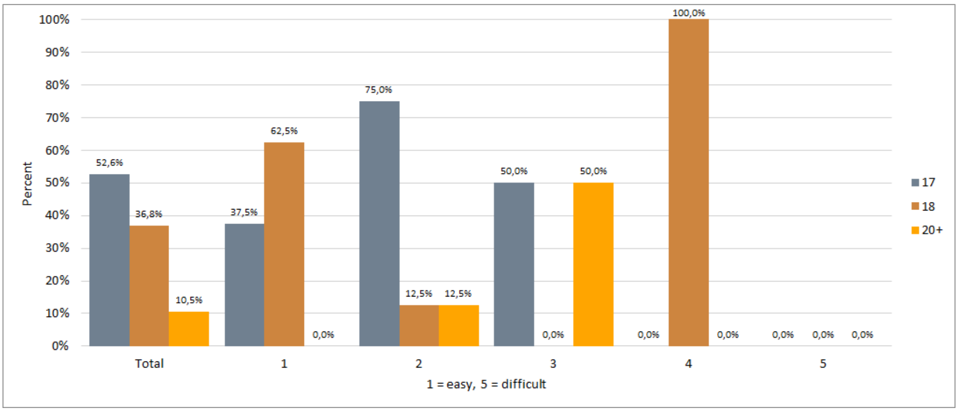

Figure 25: Age distribution of students when distinguishing between different objects in the scene

3D Models in Chemistry Experience

As the students who have no experience in using 3d models are eighteen-year-olds, one can speculate if they belong to another course than study specialisation (studiespesialisering), and have therefore not had natural science during their first year, although as this number is only 2 students, it may also be a misunderstanding.

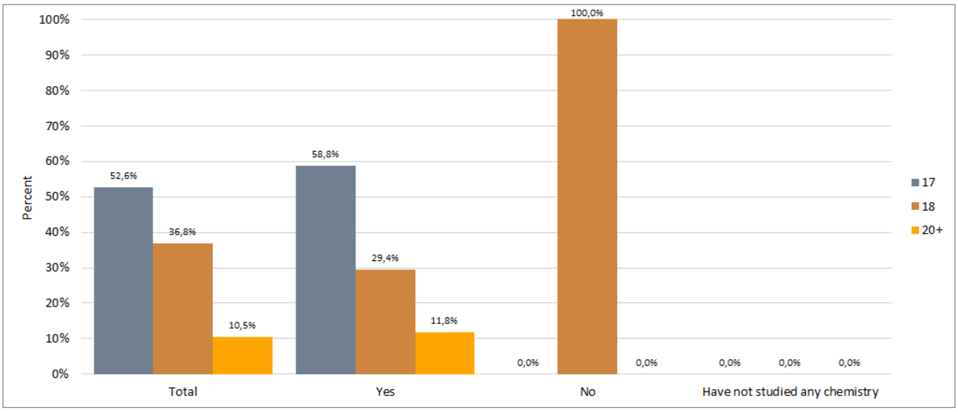

Figure 26: Age distribution of students with experience with 3D models in chemistry

Virtual Reality Compared to Books and Physical Models

No major distinction between student ages are visible in how they compare Virtual Reality to traditional learning methods such as books and physical models.

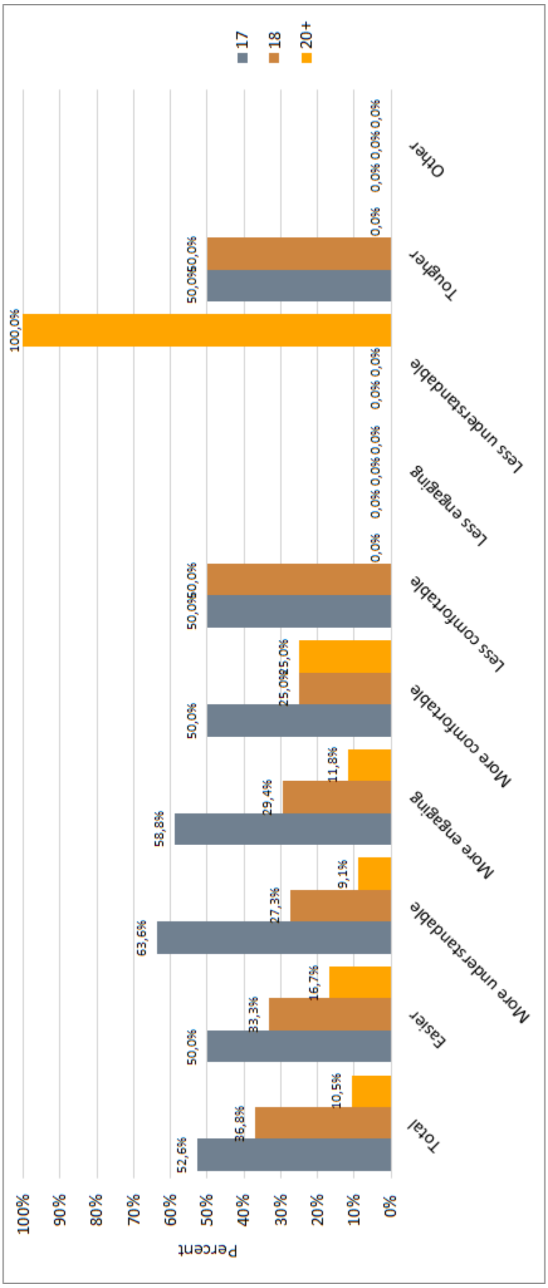

Figure 27: Age distribution of students comparing Virtual Reality with traditional methods

3.1.3 Gender Based Responses

This compares the gender of the students involved to the questions they were given. This does not include the nausea, dizziness or chemistry experience questions, as all students provided the same response to these. Furthermore, it does not include the "Why?" questions, due to the possibility of using this information to remove the anonymity of students.

Using the Controllers

During testing, women seem to have found it more difficult to use the controllers without being able to see their hands than men did. This may be because of a male affinity towards everything technical, but as the number of women who found this easy compared to men are comparable, it may also be accidental.

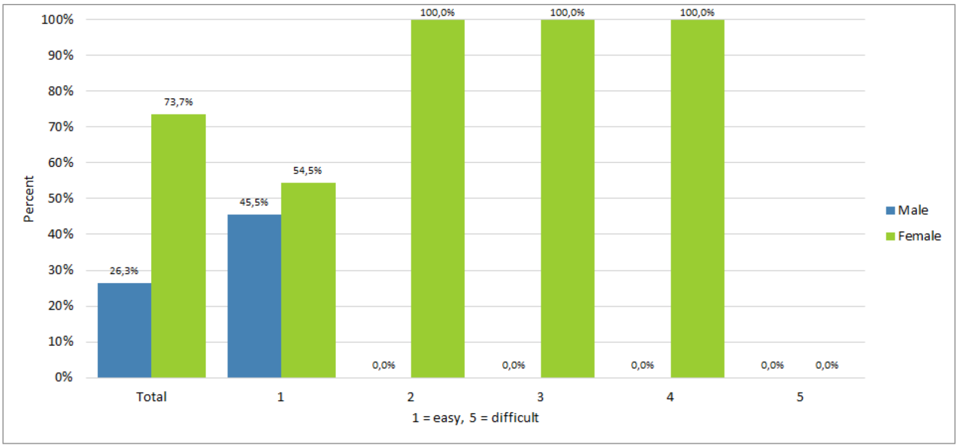

Figure 28: Gender distribution of students when using controllers without the ability to see their hands

Walking in a Virtual Room

There seem to be no significant difference between men and women regarding the experience of walking in a virtual room, as the number of female respondents are higher, heightening their statistics. and the "Difficult" and "Scary" sections only had one respondent each.

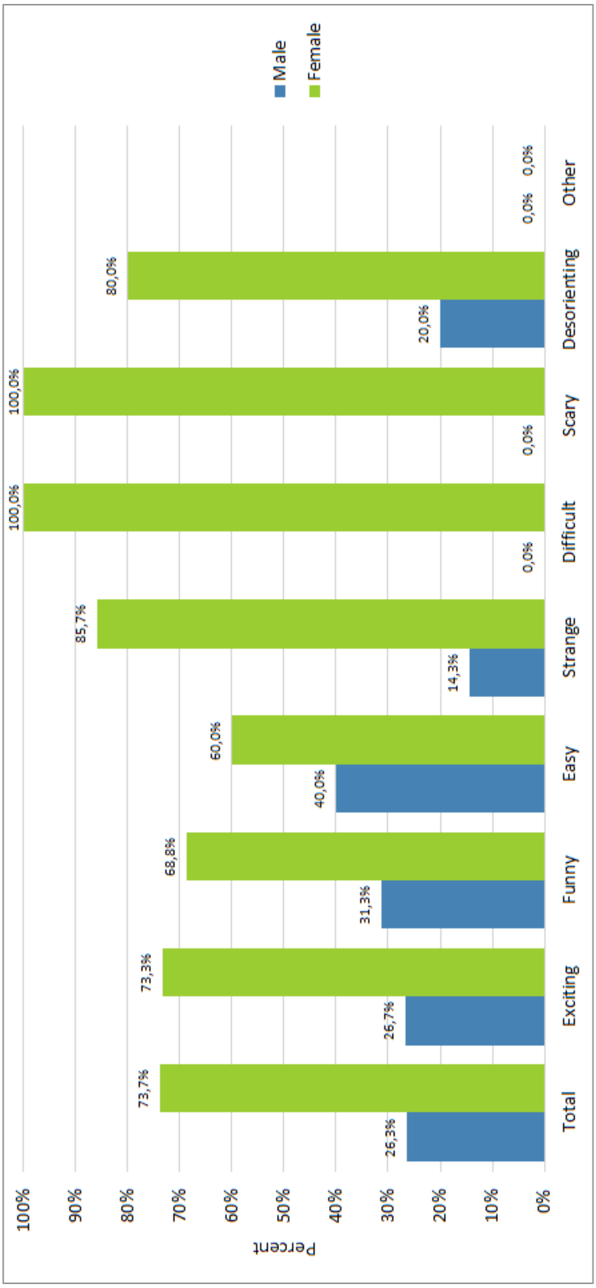

Figure 29: Gender distribution of what students felt when walking in a virtual room

Entertaining Game

As every man tested found the game entertaining and a total of four women did not, there may be a gender difference with men being more likely to find games entertaining, but due to the low number of male respondents, this is uncertain.

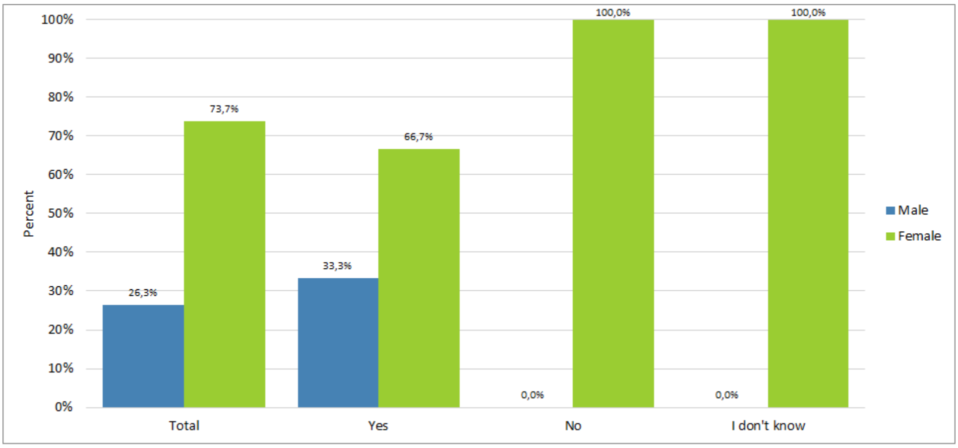

Figure 30: Gender distribution of students finding the game entertaining

Picking up Objects

Men clearly found picking up and attaching atoms and molecules easier than women. This correlates to other results, such as using the controllers, entertainment, distinguishing between objects in the scene, and comparing Virtual Reality to books and physical models.

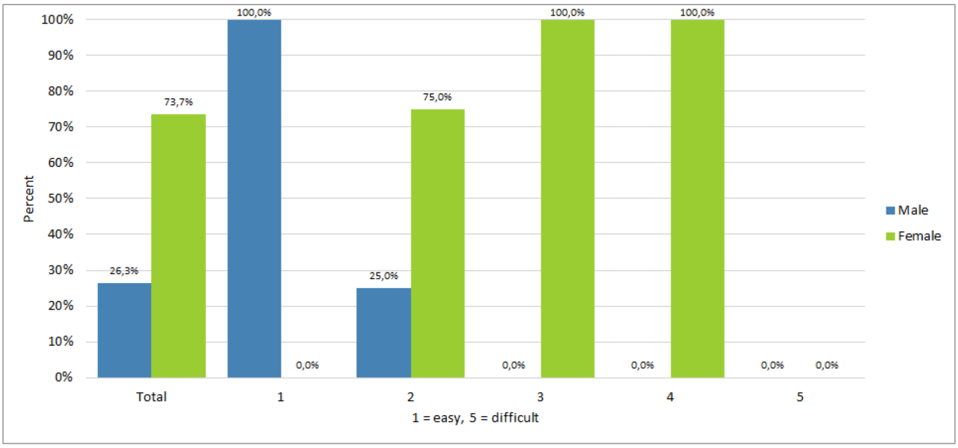

Figure 31: Gender distribution of students when picking up and attaching objects

Distinguishing Between Objects in the Scene

There is a clear distinction between men and women when it comes to distinguishing objects in the scene, as women seem to find this to be more difficult than men. However, as there are as many women who answered "2" as "1", this may be because of a belief that it is easy to distinguish between objects, but could be easier.

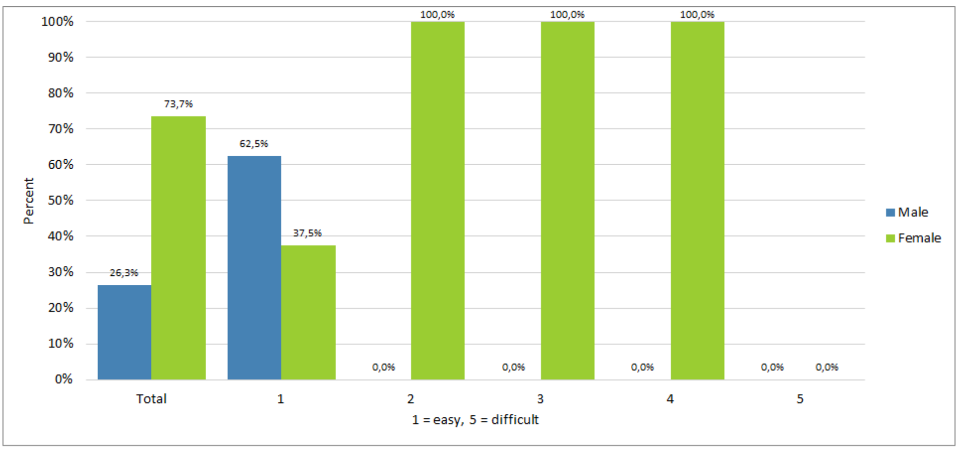

Figure 32: Gender distribution of students when distinguishing between different objects in the scene

3D models in Chemistry Experience

The gender distribution in experience with using 3D models in chemistry is even, including among the few who do not have experience in this.

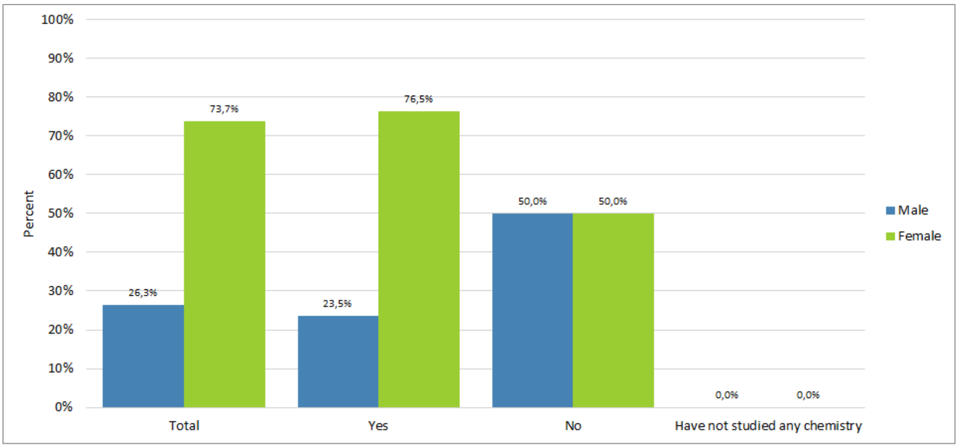

Figure 33: Gender distribution of students with experience with 3D models in chemistry

Virtual Reality Compared to Books and Physical Models

There is a divide between the genders in comparing Virtual Reality to books and physical models, as only women gave negative attributes to this comparison. However, as the vast majority of women still gave positive attributes, this may be a coincidence.

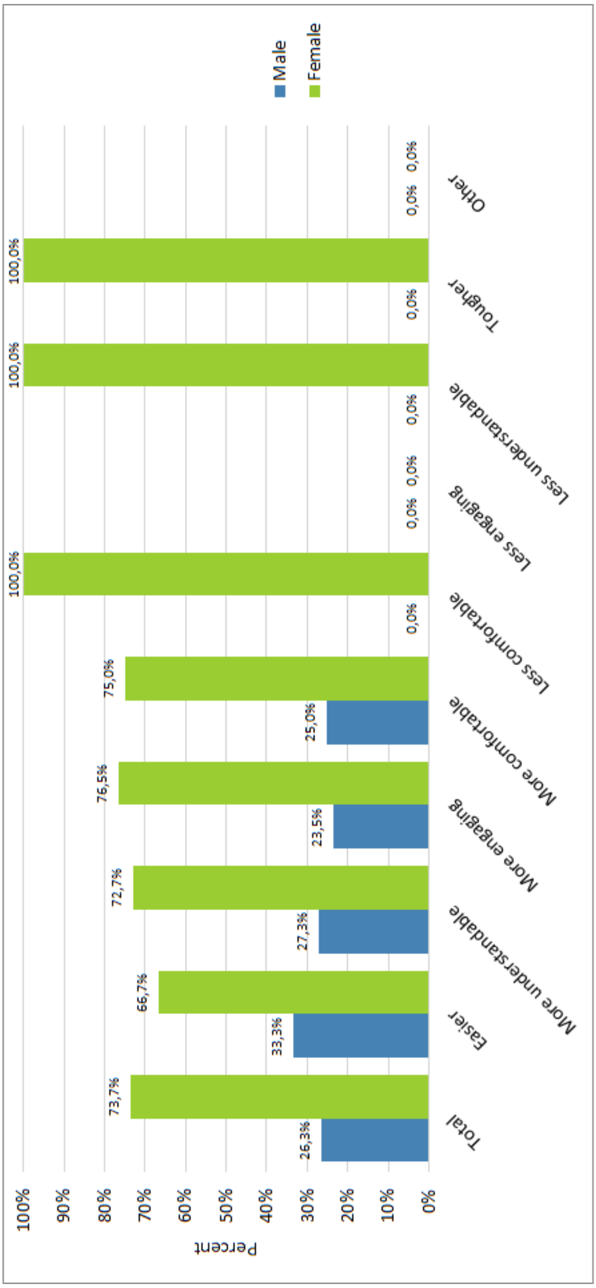

Figure 34: Gender distribution of students comparing Virtual Reality to traditional methods

3.2 Staff Responses

Responses from staff came exclusively from teachers, and every teacher was a teacher of one or more science subjects, with the majority being chemistry teachers. Five teachers agreed to an interview, and two more mistakenly responded to the student questionnaire and will be included wherever possible based on their answers there (see student age based responses 3.1.2 for figures presenting this). See appendix D for full answers.

3.2.1 Virtual Reality

Potential Problems

No member of the staff tested experienced any nausea themselves during testing, and as such they were unsure how many, if any, students would be nauseous if they tried it, but agreed there may be some small issues of this if time spent using the HMD is not regulated. On the other hand, they were somewhat torn on whether or not any injuries may occur, although the staff who believed there may be injuries pointed out that this will only happen if there is no open dedicated area for walking around in Virtual Reality.

The main potential problems of Virtual Reality pointed out by staff relates to organisation, communication and relevance. They would need for the game or otherwise software to be highly educationally relevant in order to avoid pointless play. If there are any auditory distractions, then the teacher should be in control of this, as visual contact is otherwise possible if the teachers themselves step into the Virtual Reality software in question. Organisation of larger classes would be next to impossible according to two staff members, as it would become to easy for students to distract eachother and too difficult for the teachers to maintain control.

Potential Benefits

Visualisation is unanimously a great benefit of using Virtual Reality in school related subjects, according to the staff members questioned. This would relate specifically to scientific subjects such as chemistry, biology, physics, maths and information technology. These courses heavily relies on symbolism for real world phenomena, instead of accurate naturalistic representations, and so the staff believed using Virtual Reality in these subjects would be of great help. While talking to the staff outside of the interview they also mentioned subjects like social science and languages, as they also use occasional symbolism, but struggled to mention specific examples as they were not teachers in these subjects.

Virtual Reality as a tool to aid long distance contact with students was met with minor scepticism, but this was exclusively for economic and current technological limitations. When these improve, the staff believed Virtual Reality could indeed aid long distance contact in several forms, whether it was for students who were sick or injured, or collaboration with other schools. Using Virtual Reality for testing purposes for school work was also mentioned by one staff member. This would be used to make sure students know how nature is represented in specific subjects. The staff member added that this would not be used for exams or midterms, only minor tests on single students or small groups at a time. Otherwise, the staff members struggled to come up with more potential benefits for Virtual Reality, but stressed that as long as the game or software is even mildly entertaining for the students and relevant to the subjects, there is no limit to what may be created and used.

3.2.2 Games

Potential Problems

Distraction and seriousness of the students mark the main issues pointed out by the staff. As games are designed to be entertaining, the staff were worried that the students may become too distracted to learn what they play, and instead focus on the gameplay itself. A distorted reality picture was, however, disputed amongst the staff, as some believed games may indeed give students the wrong impression of how the world works, and that game developers need to keep this in mind when designing their games. For simple visualisation such as VRChemist, however, this does not seem to be a major concern for the staff, as the models used were too simple and too close to what is thought in class to be a concern.

The potential for games to create differences between students seemed to only be a minor concern for the staff. Those who did see an issue here pointed out that the difference would relate to student interest in games, and that some students who struggle in school are themselves gamers who would benefit from such an arrangement. Otherwise the main issues relates to economy, as it may become expensive to make sure everyone can play the game, though this depends on the game and console, and reviewing student work, as some teachers may find this difficult in a new medium such as gaming.

Potential Benefits

The staff strongly believed games could increase student interest in subjects, as they would find this more entertaining than traditional learning methods, but could only agree that this would at the very least supplement learning. The classes would still continue as before, but with games as a memory or rehearsal tool rather than a replacement for traditional methods, and only in fields where visualisation is important. Otherwise, using multiplayer to improve cooperation, learning at home out of your own volition, and improved student-teacher relations were the main benefits staff could come up with for games in school work.

3.2.3 VRChemist

Only known gameplay bugs and planned features were mentioned as problems with VRChemist by the staff during testing, with the bindings not behaving properly being the main issue faced. On the other hand, the staff did not wish for any of the existing features to be removed. The concept and prototype were endearing to them, and repeated requests to create a polished, full game were heard. This includes the boxes underneath the table, as observation showed they seemed to be popular amongst both staff and students alike during testing, whether it was practising what they could do in Virtual Reality and getting used to it, stacking them to make towers, or using them as baseball bats and smash the atoms and molecules they constructed.

4 Discussion

4.1 Problems

First session

Due to arriving 15 minutes late to the first testing session, minor problems persisted throughout the day. Some students played the game for up to 5 minutes longer than others, and some interviews were interrupted from time to time while trying to supervise whoever was wearing the HMD. Minor bumps into objects in the real world also occurred, luckily without any bruising or injuries, due to the play area not being thoroughly emptied before testing. However, due to these incidents only being minor problems that are to be expected during testing, it is not believed these had any major impact on the results, and are therefore considered acceptable.

Second session

As the second session was attempted as a remote testing session, there were some issues. While the test subjects could be seen through a camera (via Skype), the screen and how the test subjects acted in game could not be viewed. This caused a lack of guidance and suggestions from the author. Furthermore, although the contact at the school had been alerted to the need for a questionnaire for students and an interview for staff, the contact was overtaxed with handling the setup for the testing and maintaining their ordinary work routine simultaneously. As the tester could not see anything beyond whoever was playing the game, a false sense of what was going on in the rest of the room was established, and the tester failed to notice this until the end of the session. The students therefore had to be sent the quiz the subsequent days, and not all students who tested responded to the questionnaire in the end. Furthermore, the two staff members who tested during this session were never interviewed, but were accidentally sent the link to the quiz and thus answered this instead.

However, while the troubles with the students had some impact on the results, it is not believed this impact corrupts this, as a one and a half week (11 days, ended on a Sunday to make it easy to remember) time limit was placed on answering the questionnaire, and as the simplicity of the game and its contents should make the experience simple and easy to remember for such a time period. As for the staff, while it is unfortunate that they were not interviewed, they did provide some answers in the questionnaire that provide a sense of what they felt during the session. As this was simple to isolate, it does not affect the student answers, but instead provides a secondary basis for staff answers.

Experience in Virtual Reality

A question that in retrospect may have been interesting to ask the test subjects was the nature of their experience with Virtual Reality. During both sessions it was made clear that several students and staff had used either a version of the Occulus Rift or the HTC Vive for various reasons at various times. This may have had a minor impact on the initial reactions of testers in their first few minutes in the game. However, as discussed in the implementation (2.1), the design and control scheme were intentionally made simple and easy to learn, and all subjects quickly adapted to the controls and environment (1-8 minutes from observation) regardless of experience.

4.2 Analysis

4.2.1 Students

Gender distribution

While many papers documenting the effect of games or technical innovation suffer from a shortage of female test subjects, this paper had an unintentional majority of female students at 63%. This oddity can be explained by the fact that one school had recently returned from a trip where the students could try out the HTC Vive, and that the female students who attended this trip were therefore more inclined to accept the request for test subjects.

As expected, there was some disparity between genders in those who thought that the game and control scheme was difficult and uninteresting, and those who thought it was easy and entertaining. This disparity is however quite small compared to the number of female students taking part in the experiment. This may be due to either the deliberate simple control scheme and game design, or the voluntary nature of this experiment, or a combination of both. Further research may be necessary to distinguish these.

Experience in chemistry

As Norwegians begin learning basic chemistry in late Secondary School (Ungdomsskole) in the Natural Science (Naturfag) course, it was expected that the past experiences would be roughly at the resulted level, with all students learning chemistry and only a small number never having used 3D models before. The latter mentioned small number of students not having used 3D models is such a small number that they may have misunderstood what was meant with 3D models, as no image or otherwise example was provided, or they may have come from a high school study without the use of these. A secondary question on the questionnaire and/or a quick explanation of what is meant by 3D models may have cleared this up, but due to its low percentage had no impact on the conclusion.

4.2.2 Staff

Organisation

Due to the response from the staff related to potential issues with organising larger classes, this should be addressed before any full use of Virtual Reality can occur in school related subjects. The simplest way of fixing this issue is to restrict the number of students in Virtual Reality at a time. This will be the natural way of avoiding organisational issues in the next few years anyway, due to cost issues with Virtual Reality gear and VR-Ready computers. By the time Virtual Reality has become affordable and available for larger classes, other studies or software may have been released that supersede this issue. If no such good solution has been found by then, it may still be easier to enforce small groups until a satisfactory solution has been found.

Visualisation

Another strong response from staff was related to the visualisation of scientific curriculum. While staff agreed that courses more closely related to the real world, such as social science and language courses, may affect the younger students' ability to differentiate between reality and Virtual Reality, the sciences do not possess this problem on a high school level. They unilaterally believed VRChemist was a great example of what Virtual Reality could do for scientific courses, and that more games/ software related to this should be made. Their reasoning for this is that many students find it difficult and boring to try to understand the visual parts of the scientific curriculum, which in turn affects their grades. With games and software showing these visual aides in a more interactive and clearer manner, this may be fixed, and as Virtual Reality brings interaction to a whole new level, this should not be understated. Further research on both games and other software for Virtual Reality exploring these other courses should therefore be conducted.

Games

The interviewed staff seemed to have a good grasp of both potential problems and benefits of using games in learning. As tends to be a problem when left alone, student distraction was a major concern, and must be addressed when used for learning. However, the staff also agreed that games would make some students more interested in learning, and that games could therefore supplement learning for those who are struggling. This confirms some other studies conducted in the field if games for education, such as Bonde et. al.'s study of chemistry games [2] and Virvou and Katsionis' geography tests [10].

4.2.3 Common

Nausea and dizziness

As no test subjects felt nauseous or dizzy during or after testing, one of the minor research questions of this paper was answered straightforward. As the staff was unsure whether or not some students would feel nausea, and with one staff member reported easy self affection of travel sickness in boats, etc., the idea that student nausea may very well indeed be hindered by using simple, large objects instead of details require further research. Time limit may also have been a major contributing factor, and further research on what this time limit should be is warranted, as this study's 15 minute time limit is mostly arbitrary, with turn-around time and learning curve included when assessing the time limit used.

4.3 Impact

As this study was only conducted on Norwegian high schools, one can argue that much of the lessons learned are only applicable for use in Norway, if at all due to the low number of test subjects. However, Virtual Reality should still have a strong potential to improve visualisation in the scientific curriculum, and more research should be done to verify this.

As for the impact in Norway, this study shows that the path is open for the use of Virtual Reality in high school education. Nausea and dizziness are not applicable when set on a time limit, injuries will not occur as long as someone watches over the students, and the improvements to visualisation may well justify the price tag. The only real issue is finding games or other software related to the students' curriculum, and this issue will degrade on the coming years as more companies release Virtual Reality specific software in these areas. Although for now Virtual Reality should not be part of a normal student's curriculum, high schools should begin to explore the possibility for this soon, so that experiences can be gained posthaste.

5 Conclusion

Depending on the subject represented, Virtual Reality may increase student interest and understanding in the material presented to them. In subject such as physics, chemistry, biology and sciences, models are almost exclusively used to represent the curriculum taught at a high school level, rendering any chance at gaining a false sense of reality or mixing experiences with real-life experiences low. While there may be an initial difference to gender based interest in using this technology, the ability to supersede the boundaries of real-life models and applications on a regular screen may even this out over time given a commitment to the usage of Virtual Reality as a learning tool.

5.1 Future Work

Virtual Reality in High Schools

Several key areas have been explored, but not proven in this paper. Any and all of these areas need more thorough testing, both in Norway and abroad. Nausea and dizziness prevention using either simple geometry and colours or otherwise deliberate lack of detail, or exploring time limits that can prevent this, both for new players and experienced ones require further research and comparison between various games. Finding new ways to organise large groups i Virtual Reality, so that larger classes instead of just small groups can all use Virtual Reality simultaneously. Most importantly for this paper, though, Virtual Reality as a visualisation tool in schools is a major potential area to explore. As mentioned in this paper, visualisation in certain areas within scientific subjects such as chemistry, physics and biology is needed and desirable by students and teachers alike, and is therefore open to research.

VRChemist

The feedback gained on VRChemist shows that, as a concept, the game is highly desirable amongst students and teachers alike. There are several ways to improve upon the game in the future, some of which include:

- General bug fixing and improvement
    - This prototype build of VRChemist had an outstanding issue with larger molecules exploding, and was therefore deliberately limited in other areas. After this bug is fixed, these other areas can be strongly improved upon.

  - More atoms and non-arbitrary regulation of size of atoms would drastically increase the amount of things to do in the game.
  - Checking what molecules are created by the player at any given point would increase the understandability of the game.
  - More tasks that check if an action has completed the task before providing another would help make the game more dynamic.
  - General binding improvement is a much sought after wish from testers, and regulating these to align with the centre of the atoms they attach to (as well as closer to them) would help a lot.
  - Potentially improving the environment to be more exciting, but still not distracting would help with the general feel of the game. Sound and music may also help with this, especially when attaching bindings and molecules, but with an option to turn these off, so that they cannot disturb or mute out the teacher.
  - Adding simple atomic codes to the atoms' textures, so that they become recognisable without having to check up what they are.
  - The ability to spawn atoms and bindings into the world as well as delete them will remove any potential problems with having not enough of certain atoms or having created too much that end up floating around. An extra ability to copy and paste molecules would also aid the creation of more complex molecules, as many of these have repeating patterns.

- Adding a tutorial level
  - The current build has an inbuilt introduction to Virtual Reality in the form of simple boxes that can be thrown around at will. This could instead become a distraction after some use, however, and should be placed in its own tutorial scene. This tutorial could then potentially have more things to do as well, in order to truly understand how to interact with Virtual Reality, possibly reminiscent of the HTC Vive for Unity tutorial at raywenderlich.com [11].
- Different modes
  - Some requests made by testers, in particular the teachers, are contradictory to eachother, but not necessarily unachievable together.
  - The ability to lock bindings in certain angles to eachother for younger students, or allowing these to be free so that older students can be tested on their angular accuracy and understanding of this.
  - The ability to create molecules without the need for bindings was also requested, and is only visually possible in the current build as atoms do not collide or attach to eachother.

  - Various modes for the teacher to test their students using tasks the teacher set up beforehand instead of the game may also increase the range of what the game can be used for.
  - Different scoring modes, such as time spent, accuracy, or amount of tasks completed could also help with both student testing and competition between students.

- Adding multiplayer
  - Multiplayer may increase the teacher's control over what the students are doing, as it gives the teacher a chance to meet and interact with the students in game, as well as the ability to review their progress.
  - More and more schools are requesting the funding to cooperate with other schools on an international level. One of the schools contacted in this study is such a school. In order to improve and maintain a steady stream of cooperation, the schools need ways to work in tandem with eachother, preferably in real-time. A multiplayer mode was therefore requested for future iterations of VRChemist so that this cooperation may flourish.

- University level gameplay
  - One teacher noted during a non-interview discussion that a game such as VRChemist could potentially be used on a University level to teach Bachelor and Master students, and even potentially to aid Ph.D students to visualise their work. What these studies would need from VRChemist to achieve this, if possible, would need to be researched further.

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A Participation Request Agreement

A.1 Norwegian (Norsk Bokmål)

Vennligst påse at selv om skrivet nevner Google Skjema ble Questback brukt istedet. Skjemaet ble ikke oppdatert tidsnok for å fikse denne forskjellen.

Forespørsel om deltakelse i forskningsprosjektet

”VRChemist"

Bakgrunn og formål

I denne studien er formålet å analysere elevers interesse for kjemi, VR, og spill i læringsmål i videregående skoler, samt å analysere læreres og andre videregående stillingers standpunkt på bruk av VR og spill i samme læringsmål. Dette blir gjort i form av en master oppgave ved NTNU campus Gjøvik.

Alle deltakere i denne studien er frivillige og er selv ansvarlige for å lese og forstå innholdet i dette dokumentet før signering og deltakelse.

Hva innebærer deltakelse i studien?

For elever vil studien innebære en rask opplæring i bruk av HTC Vive kontrollene og headsettet, etterfulgt av maks 15 minutter inne i spillet som kan avbrytes av eleven når som helst uavhengig av grunn. Mens eleven er inne i spillet vil deres oppførsel i spillverdenen bli observert og notert om det er observanten mener er nyttig informasjon. Dette omhandler uvanlig oppførsel eller reaksjon av eleven eller av selve spillet (bugs) mens testen pågår. Etter de 15 minuttene, vil eleven bli spurt om å svare på et raskt spørreskjema i form av Google Skjema (Google Forms), hvor spørsmålene inkluderer alder, kjønn, og interesse og forståelse av spillet.

For ansatte vil studien innebære en rask opplæring i bruk av HTC Vive kontrollene og headsettet, etterfulgt av en egenvalgt tid inne i spillet som avbrytes av ansatt selv uavhengig av grunn. Mens den ansatte er inne i spillet vil deres oppførsel i spillverdenen bli observert og notert om det er observanten mener er nyttig informasjon. Dette omhandler uvanlig oppførsel eller reaksjon av den ansatte eller av selve spillet (bugs) mens testen pågår. Et intervju vil etterfølge denne spilltiden, hvor spørsmålene inkluderer interesse og forståelse av spillet, samt tanker ovenfor VR og spill i skole sammenheng generelt.

Hva skjer med informasjonen om deg?

Alle personopplysninger vil bli behandlet konfidensielt. Kun master student og veileder vil ha tilgang til denne informasjonen. Navn og andre personopplysninger vil ikke bli brukt i oppgaven og vil derfor ikke kunne gjenkjennes i publikasjonen.

Prosjektet skal etter planen avsluttes 01.06.2018. Alle personopplysninger samlet inn vil bli slettet senest 2 uker etter prosjektavslutning. Data ansett som ikke inneholder personopplysninger kan bli lagret på ubestemt tid.

Frivillig deltakelse

Det er frivillig å delta i studien, og du kan når som helst trekke ditt samtykke uten å oppgi noen grunn. Dersom du trekker deg, vil alle opplysninger om deg bli anonymisert.

Dersom du ønsker å delta eller har spørsmål til studien, ta kontakt med master student Per-Arne Waaler Stenshagen ved NTNU Gjøvik via email: pastensh@stud.ntnu.no eller veileder Rune Hjelsvold ved NTNU Gjøvik via email rune.hjelsvold@ntnu.no.

Studien er meldt til Personvernombudet for forskning, NSD - Norsk senter for forskningsdata AS.

Samtykke til deltakelse i studien

Jeg har mottatt informasjon om studien, og er villig til å delta

____

(Signert av prosjektdeltaker, dato)

A.2 English

Please note that while the contract mentions Google Forms, Questback was used instead. The contract was not updated in time to fix this difference.

Request of participation in the research project

"VRChemist"

Background and purpose

The purpose of this study is to analyse student interest for chemistry, VR, and games for education i high schools, as well as analyse teachers' and other high school staffs' stance on the use of VR and games in the same curriculums. This is done in the form of a master thesis at NTNU campus Gjøvik.

All participants in this study are volunteers and are themselves responsible to read and understand the contents of this document before signing and participation.

What does participation in the study entail?

For students the study will entail a quick tutorial in the use of the HTC Vive controllers and headset, followed by a maximum of 15 minutes inside the game which can be interrupted by the student at any time regardless of reason. While the student is inside the game their behaviour in the game will be observed and noted down if there is anything the observer deems as useful information. This entail unusual behaviour or reaction by the student or by the game itself (bugs) while the test is underway. After the 15 minutes, the student will be asked to respond to a survey in the form of Google Forms, where the questions include age, gender, and interest and understanding of the game.

For staff the study will entail a quick tutorial in the use of the HTC Vive controllers and headset, followed by a self chosen amount of time inside the game which can be interrupted by the student at any time regardless of reason. While the staff member is inside the game their behaviour in the game will be observed and noted down if there is anything the observer deems as useful information. This entail unusual behaviour or reaction by the student or by the game itself (bugs) while the test is underway. An interview will succeed this playtime, where the questions include interest and understanding of the game, as well as thoughts about VR and games i school context in general.

What happens to your information?

All personal information will be treated confidentially. Only the master student and supervisor will have access to this information. Names and other personal information will not be used in the thesis and will therefore not be recognisable in the publication.

The project is scheduled to end 01.06.2018. All personal information gathered will be deleted at latest 2 weeks after the project has ended. Data that is not regarded as personal information may be stored indefinitely.

Voluntary participation

You are a volunteer in this study, and can at any point withdraw your consent without stating a reason. If you withdraw, all information about you will be made anonymous.

If you wish to participate or have questions regarding the study, please contact master student Per-Arne Waaler Stenshagen at NTNU Gjøvik via e-mail: pastensh@stud.ntnu.no or supervisor Rune Hjelsvold at NTNU Gjøvik via e-mail rune.hjelsvold@ntnu.no.

The study has been reported to the Norwegian Centre for Research Data, NSD.

Consent of participation in the study

I have recieved information about the study, and are willing to participate

____

(Signed by project participant, date)

B VRChemist Testing Walkthrough

B.1 Setup Beforehand:

- The game uses HTC Vive with controllers, and requires SteamVR to work.
- The game needs no other software or plugins to work. Double-click on VR-Chemist.exe to start.
- A restart button is not available. Close the game and start over to reset it. Resetting SteamVR is not necessary.

B.2 This is How You Begin:

- Please read and sign the contract and deliver this to whoever is responsible.
- Only two buttons on the controllers are used in the game:
  - The disc where the thumb rests operates teleportation. Hold the button and point towards the ground to see where you will end up. Release to teleport there.
  - The trigger-button behind the controller where the index finger will be operates grabbing. Bring the controller (when inside the game) into the object you want to grab and hold the trigger. Release the trigger to release the object.
  - Familiarise yourself with what the two buttons feel like before putting on the headset, as you cannot see what your finger are doing when you are inside VR.
- The headset has straps one the sides and at the top of the head which you can use to tighten and loosen as you wish to make the experience more pleasurable.

B.3 Inside the Game:

- Atoms (oxygen, hydrogen, carbon) are placed on the table and are marked with text next to their starting position. Atoms do not react with eachother, and can be placed inside eachother if desirable.
- Bindings are also found on the table in the form of white sticks. If you touch the end of the binding with and atom, the atom will attach to the binding. Take hold of both and pull them apart to remove them from eachother.
- On the board on the wall there are three simple tasks you can try out. If you have problems viewing these well enough, teleport closer to see clearer.

- Underneath the table there are boxes. These boxes have regular VR physics and interaction, and can be thrown around and played with generally as you would with real life boxes. Play with these if you are bored or just want to try more things.

B.4 After the Game:

- If you are a student, please answer a quick survey regarding what you have just experienced. The survey takes 5-10 minutes per person.
- If you are an employee, please participate in an interview with responsible master student. The interview takes 5-15 minutes per person.

C Student Answers, Translated to English

C.1 Age

Age	Amount
15	0
16	0
17	10
18	7
19	0
20+	2

Table 1: Student age

C.2 Gender

Male	5
Female	14

Table 2: Student gender

C.3 Do You Feel Any Nausea After Using VR?

Yes	0
No	19
I don‘t know	0

Table 3: Student nausea

C.4 Do You Feel Any Dizziness After Using VR?

Yes	0
No	19
I don’t know	0

Table 4: Student dizziness

C.5 How Was it to Use the Controllers Without Being Able to See Your Hands?

1 = easy, 5 = difficult

1	11
2	4
3	3
4	1
5	0

Table 5: Student controller difficulty of use

C.6 How was it Walking Around in a Virtual Room?

Exciting	15
Funny	16
Easy	5
Strange	14
Difficult	1
Scary	1
Disorienting	5
Other	0

Table 6: Student walking in a virtual room

C.7 Do You Think the Game was Entertaining?

Yes	15
No	2
I don't know	2

Table 7: Student entertainment

C.7.1 Why?

- It was entertaining as you can build what you want and they blow up sometimes. It was also educational and exciting.
- I have always felt that building molecules with molecule sets is very fun, possibly the best part of chemistry. When you get a big room with big atomic models, the fantasy is almost the only limit. No wonder it becomes fun. Wish you could build bigger molecules since I like building big organic molecules. But since it was this fun with the small molecules, I can only imagine how interesting this would be with big molecules.
- Because it was fun to visualise the atoms, what they look like, and build the atoms together!
- It was easy to understand what you were supposed to do. The functions worked and you can see the atoms in a slightly different way.

- Fun to play with the physics in a virtual world. Fun to complete tasks. Really fun way to learn.
- I think this is a useful tool that will be applicable in education. It was fun to try something new, and it was interesting to experience being in a virtual room.
- It was an exciting experience and it was fun to do something you usually don't do.
- It was fun, because it was a new, practical and different interpretation of molecules and how you could learn simple, basic chemistry.
- There were different tasks that were interesting. After you completed the tasks you could do what you wanted, in other words play, which was fun.
- I think it was fun to get to try this. Exciting to do chemistry in a different way than what we are used to. At the same time it was a bit strange, and you felt you lost control over where you were at different times.
- It was a good way to repeat a bit of chemistry.
- It was something new, something you don't do so often! It is a new way of learning chemistry.
- Fun to try. Weird to go around the room, while everything moves. Need to do this more.
- Could possibly have been more tasks... and more to look at around...
- Fun and a new way to learn.
- A bit few options.
- It was a bit simply built, OK tasks but did not get feedback if you did it right or wrong. Missing double bindings and angles in the molecules. A bit more subject related challenge.
- New way to work. Gives a better impression of this to connect atoms.

C.8 What was Picking up and Attaching Atoms and Molecules Like?

1 = easy, 5 = difficult

1	3
2	8
3	4
4	4
5	0

Table 8: Student picking up objects

C.8.1 Why?

- It worked well and when I picked them up they came with me. Sometimes things remained hanging. You couldn't teleport with molecules.
- The controllers worked well and coordinated well with my hands. I was surprised at how easy it was to use the VR hands.
- Sometimes the atoms moved when you put together large molecules. Otherwise it was really easy.
- It reacted as it was supposed to with the controller.
- A bit difficult, but only because I just used one hand. Finished molecules could float away if you gave them a push. A bit difficult to make double bindings, but otherwise very good and easy.
- Hydrogen peroxide was perhaps somewhat challenging, but it was physically easy to perform my tasks.
- It was unusual in the beginning, but once you got used to the movements it went well. You could also think in a different way, since you usually draw molecules on a paper. Since you had to make the molecules yourself, it felt a bit confusing, while it was also fun.
- Because I only had one controller, it was difficult to separate the molecules that were made.
- It was easy to pick up the atoms, but when the atoms collided into eachother they were pushed further away. They didn't stick properly. Was also a challenge to separate them again.
- Sometimes they began to spin with eachother, and fly around the room without me having full control over them.
- They attached easily.
- A bit difficult to understand in the beginning, but very easy after trying it a few times.
- Because it didn't seem as the molecules would attach themselves. It also didn't work to make double bindings because then the molecules "flew" away.
- Was a bit hard when they suddenly began to fly away and move around without doing anything.
- It was a simple task to stretch after pushing buttons to pick up objects.
- Difficult to get close.
- It was not that easy to understand where the bindings should be placed or how many bindings there are per atom. Is this the correct size of the atoms? It was fine to put them together.
- Simple and easy. Missing a spot to place the completed molecules, as well as a potential blueprint.

C.9 What was Distinguishing Between the Different Atoms and Molecules You Used/ Made Like?

1 = easy, 5 = difficult

1	8
2	8
3	2
4	1
5	0

Table 9: Student distinguishing objects

C.9.1 Why?

- You just had to look at them and you saw.
- Clear, nice colours, black is black, red is red and white is white.
- Because they were in different sizes and colours, as expected.
- Well marked with colour and name.
- When the atoms have different sizes and colours it is easy to distinguish between them.
- It was nice that they had different size and colour, in accordance with what we use at school. In addition their places where directly named.
- It was easy to see what is what because the colours and names were there.
- You looked at the atoms. It was fun to project the atoms after having learned about them in theory.
- I already knew what many of them were and what they looked like.
- I think this was very nice.
- They were named.
- Clear and distinct colours, sizes. Easy to take a hold of.
- Was a bit straightforward.
- It was effective to use different colours and sizes on the different atoms, and good that they were named at the start.
- Good naming.
- OK, could have been more tasks and feedback if you had done it correctly.
- It went well enough. Miss a code on each molecule, where for example Hydrogen could have one available slit in its shell to connect to other atoms.

C.10 Do You Have Experience With Chemistry From Former or Ongoing Courses?

Yes	19
No	0

Table 10: Student chemistry experience

C.11 Have You Ever Used 3-Dimensional Models When Learning Chemistry Previously?

Yes	17
No	2
Have not studied any chemistry	0

Table 11: Student 3D models in chemistry experience

C.12 What was Using VR Compared to Books and Physical Models Like?

Easier	6
More understandable	11
More engaging	17
More comfortable	4
Less comfortable	2
Less engaging	0
Less understandable	1
Tougher	2
Other	0

Table 12: Student VR compared to traditional methods

D Staff Answers, Translated to English

D.1 VR Problems

1. Do you think the students will have problems with balance, nausea or dizziness even if the use of VR is regulated?
    - Don't know. Some maybe, but not most.
    - Not after a while, you need to get used to it.
    - Maybe afterwards, not sure.
    - No, not as long as you check yourself.
    - No, I get easily afflicted myself, but I'm OK.
2. Do you think the teachers will have communication problems with the students in VR?
    - No, but it depends on the teacher.
    - If you can't see what they are doing, it can become difficult to maintain contact with them.
    - No.
    - Yes, I did. The messages need to come from within VR instead.
    - If there is no headset (for sound), no, otherwise you need access to the sound.
3. Do you think there is any danger of injury with the use of VR?
    - No.
    - Short time sickness and other short lasting problems, nothing bad.
    - Depends on the surroundings, you could crash into stuff.
    - Depends on the surroundings. Its a bigger chance to damage the equipment.
    - No, think it will be fine.
4. Do you see other potential problems with VR in education?
    - Organisation for large classes, should only be used by a few at a time.
    - Organisation for large classes. Depends on the (student)level, many young can be chaotic. Older students in smaller groups should go better.
    - No, not as long as it works as intended.
    - So new that you see more possibilities than problems.
    - Probably to make it relevant, rather than just a game, though this is not

a major danger. Profits are bigger than the challenges.

D.2 VR Benefits

5. Do you think VR can replace parts of the traditional learning methods?
    - Yes, many things. Exploration in particular. Everyone could come and watch. Organic chemistry reaction would be one area.
    - Everything to do with visualisation. Big opportunities within chemistry, biology, physics, animations and sciences in general.
    - Yes, probably.
    - Yes, definitely. Only a matter of what exists, must be made first.
    - Could add visualisation, could especually be used in natural science and chemistry, potentially in other sciences.
6. Do you think VR could help students visualise things, such as molecules, better in VR?
    - Yes.
    - Yes!
    - Yes.
    - Yes, that's probably its strongest side. To zoom in is a great strength, for example dissection in biology.
    - Yes.
7. Do you think VR could improve long distance contact with students from other schools or non attending (sick/ injured) students?
    - Not yet due to technological and economic limitations, but in the long run, yes.
    - Depending on Internet speed and technology, yes.
    - Yes.
    - Yes, it should.
    - Yes, definitely. Think it would help.
8. Do you see other potential benefits with VR in education?
    - Assessment of what happens with tests and such.
    - Yes, but unsure of what. Again, visualisation. Infinite amount of possibilities.
    - Cooperation with others who are not present, exploring models, visualisation. Only limited by software.
    - Yes, as long as there is a digital version it could replace much of the usual. Can be used in many subjects. Difficult to see the limit.
    - Could be a motivator for some, as a motivating game.

D.3 Game Problems

9. Do you think games could be distracting for the students?
    - No, it depends on the teacher.
    - Depends on how its organised. It could be chaos. Good arrangements hinder problems.
    - Yes, to a relatively large degree for some.
    - Both. Depends on the game, you can't have non relevant distractions in the game.
    - Yes, they are. But can get better of the teacher meet the students in the area so that they know what to do.
10. Games often show a different world than the one we are used to in reality or in books to achieve a higher user friendliness and interest. Do you think games can make children/ youth believe in a false reality picture of what they learn if the game is not good enough?
    - No, especially not in the sciences. Unlikely.
    - All models are a simplification of reality, but it depends on what ti is used for. Some areas could be problematic, such as for example ski jump visualisation, or political reality changes.
    - Yes.
    - Yes, the game designer must consider this. The model is often easier to remember than the scholarly its based on.
    - Not in model related areas. As long as its limited to this, it should be fine.
11. Do you think games will create differences between the students to a larger degree than with classical learning methods?
    - No, not necessarily.
    - Those who are good (at learning) could have some problems, those who have problems could learn more. Difficult to say. If the school offers it equally for all, it should not be a problem and everyone will earn from it, but some will learn it faster than others.
    - Depends. Those who are better at playing games will get a head start, but nothing else.
    - Yes, those who are used to games will have an advantage.
    - Depends on the availability. Not sure.
12. Do you see other problems with games in education?
    - Probably problems, but unsure. More important with the possibilities.

- Availability, but this is more economical.
- Scholarly relevant games are often not that exciting, non relevant games are distracting.
- Economical problems, what is out there and what it costs.
- Difficult to keep it serious, you need to give them clear tasks. Could be difficult to grade the completed work.

D.4 Game Benefits

1. Do you think games could make students more interested in the subject than classical learning methods?
    - Yes.
    - Yes!
    - Yes.
    - Yes, as ling as it creates wonder.
    - Yes. But could be a challenge to some.
2. Do you think games could teach more/ better than classical learning methods?
    - Not necessarily more, but can definetly supplement.
    - In some areas yes. Again this falls on visualisation.
    - Yes, in some areas.
    - Both, with a supervisor it should be fine. On your own it could be a problem.
    - Within visualisation, yes.
3. Do you see other potential benefits with games in education?
    - No, can't think of anything. There must be a balance.
    - Visualisation!!!!
    - Multiplayer and cooperation.
    - You feel more like learning at home.
    - The education and the teachers will seem more attractive for teaching, as they meet the students halfway.

D.5 VRChemist

16. Are there any problems with VRChemist that should be fixed?
    - A bit tricky to attach bindings, especially double bindings. Didn't see much with contact lenses.
    - Bindings in a straight line. Fine tuning and angles. A bit more pre determined geometry. Infinite amount of atoms. Atoms should be smaller or

let you minimise them when your done.
- Bindings don't move as they're meant to, but shouldn't be pre determined on the atoms as this would be boring. A bit more educational. Potentially shell models instead of spheres.
- A bit difficult to build the models, could potentially have pre-determined places to make it easier.
- A bit tidier molecules, that you know what you are building. Tetrahedron structure could be useful. Visible electrons could also be useful.

17. Is there anything VRChemist did so well that it should be kept?

    - Tasks were good, the program is good but difficult, great to see 3D versions of molecules.
    - The entire base concept. Very exciting to think of a full version of the game.
    - The boxes helped, works well to build molecules like this.
    - Very straightforward, you can pick up whatever you want. Good that you can see the models from all sides.
    - Most of it. Some improvements are needed, but most is good as is.