

VIRTUAL REALITY TOOL FOR TEACHERS

Inti M.F. Bistolfi

s1814346

B.Sc. Thesis

JANUARY 2020

FACULTY OF ELECTRICAL ENGINEERING, MATHEMATICS & COMPUTER SCIENCE

SUPERVISORS

DR. J. ZWIERS

DR. A. KAMILARIS

UNIVERSITY OF TWENTE.

ABSTRACT: The use of virtual reality (VR) in the classroom shows potential for improvement on the student's ability to learn, however a way to enable teachers to easily incorporate VR into their lessons has yet to be created. Therefore, a VR lesson, showing the mechanism of DNA replication, has been made in co-creation with a teacher to identify important aspects of a VR tool for teachers. These aspects included being able to add questions, text, voice-overs, interaction and animations.

Extended abstract

Virtual reality (VR) is making a rise in the educational field. However, the bridge between teachers and virtual reality still needs to be built. For that reason, this aim of this research was to discover what aspects and features are needed and wanted in a virtual reality tool for teachers where a teacher can make guided lessons with the use of premade 3D models from third parties. This main objective was achieved by making a prototype of a VR lesson with the help of co-creation by a teacher to identify aspects that a VR tool should need. Literature research has shown that no virtual reality tools have been made to help high school teachers make a VR lesson. Additionally, research has shown that the use of VR in the classroom can be beneficial for the knowledge gain and student achievement of a student. A list of requirements has been made for the lesson and for the virtual reality tool. With these requirements, the idea arose to make a platform where the teacher can alter existing 3D environments to make a personalized VR lesson. The co-creation of a lesson should be in-line with this idea. Additionally, the subject of the lesson was chosen to be DNA replication. Moreover, an investigation was done into the practical requirements of the used VR gear and it was concluded that a standalone VR device like an Oculus Go should be chosen to develop the lessons for. A specification of the lesson was formed which specified the detail of the 3D model, the animation on DNA replication that the teacher requested and that the lesson should support voice-overs and MPC-questions that would later be delivered by the teacher. After the lesson was made, an evaluation was done both by the teacher that helped make the lesson and the students that had taken the lesson and the results were positive. Moreover, the majority of the students gained knowledge on the subject. The virtual reality lesson that has been created has given a lot of insight into the possibilities of the development of a virtual reality tool for teachers. Aspects that would be needed in such a tool would be the possibility to add animations, the ability to add text, questions, and voice-overs, and the option to have different stages and let the teachers map the interaction between stages. Additionally, a library of 3D models, animations and environments for teachers is necessary.

Acknowledgement

I would like to express my gratitude to my first and second supervisor, dr. Job Zwiers and dr. Andreas Kamilaris, for providing me with feedback, new ideas and valuable guidance throughout the course of this project.

I also want to thank MSc. Melde Gelissen for helping me during this project by answering many questions, providing useful feedback, co-designing a VR biology lesson with me and letting me test the virtual reality lesson on your students. I also want to thank all the students that cooperated in this feedback session.

Last but not least I want to express my thanks to itslearning to provide me with this project, bring me in contact with teachers and to give me a place to work.

Table of Contents

Abstract	1
Acknowledgement	2
Table of Contents	3
List of Figures	5
Chapter 1 - Introduction	6
Chapter 2 - State of the art on a virtual reality tool for teachers	8
2.1 The added benefit of a virtual reality tool	8
2.2 The virtual reality implementation tool	10
Chapter 3 - Requirements capture & Ideation	16
3.1 Storyboard, user story and user scenario	16
3.2 Requirements	19
3.3 Practical requirements	22
3.4 Lesson content ideation and evaluation	25
3.5 Ideas for the virtual reality tool	34
Chapter 4 - Specification	38
4.1 Development of lesson content for DNA replication	38
4.3 lesson specifications	40
Chapter 5 - Realisation	41
5.1 The user interface prototype	41
5.2 The virtual reality lesson	46
Chapter 6 - Evaluation	52
6.1 Requirements vs implementation	52
6.2 Feedback of the teacher	53
6.3 Feedback from the students	54
Chapter 7 - Conclusion	60
Chapter 8 – Future Work	62
Appendix 1: start screen of the interface prototype	63
Appendix 2: screen 1 of the interface prototype	64
Appendix 3: screen 2 and 2b of the interface prototype	65
Appendix 4: screen 3 and 4 of the interface prototype	66
Appendix 5: screen 5 and 6 of the interface prototype	67
Appendix 6: screen 7 and 8 of the interface prototype	68

Appendix 7: screen 11 and 12 of the interface prototype	69
Appendix 8: Detailed view of interaction in the interface prototype	70
Appendix 9: StageHandler.cs	71
Appendix 10: Interactable.cs	76
Appendix 11: AnimationScript.cs	79
Appendix 12: Reticule.cs	80
Appendix 13: Pointer.cs	81
Appendix 14: PlayerEvents.cs	84
References	88

List of Figures

Figure	page
1. 3D model of half of the eye with different layers.....	28
2. 3D model of half of the eye including vessels and muscles.....	28
3. 3D model of the eye with different layers, an outside view, and an inside view of the eye.....	28
4. 3D model of the half of an eye, realistically made.....	29
5. 3D model representing the heart and the blood vessels of the lungs.....	31
6. 3D model of the heart and lungs.....	31
7. 3D model of the inside of a blood vessel.....	32
8. 3D model representing the cell and the cell nucleus, including the inside of the cell nucleus.....	33
9. 3D model of the cell and the cell nucleus.....	34
10. 3D model of DNA.....	34
11. Example of using a 3D environments search library and a 3D environment to make virtual reality lessons.....	37
12. A schematic overview of the composition of DNA.....	40
13. DNA replication fork, illustrates the replication of the leading and lagging strands of DNA.....	40
14. Interface of itslearning when a teacher makes a new assignment.....	43
15. Overview of all screens of the prototype of the user interface.....	44
16. Overview of interaction between screens of the user interface.....	45
17. The DNA separation model before the start of the animation.....	48
18. The DNA separation model during the animation process in which the two DNA strings are separated by the enzyme helicase.....	49
19. The DNA separation model during the animation process in which the two DNA strings are connected with new nucleotides with the enzyme DNA polymerase.....	49
20. A screenshot of a screen recording of the VR lesson about DNA using the Oculus Go. The screenshot shows one of the multiple-choice questions with the four possible answers.....	51
21. User pointing at deoxyribose (sugar) in the VR lesson.....	51
22. User pointing at guanine in the VR lesson.....	51

23. The SUS points per answer.....	58
24. Diagram of the answers of students to the student questionnaire.....	60

Table	page
1. MoSCoW method for the teacher interface of the virtual reality tool.....	21
2. MoSCoW method for the virtual reality lesson.....	22
3. The student survey that was given to students after participating in the VR lesson.....	60

Chapter 1 - Introduction

Technology has become increasingly important in the field of education. Nowadays almost every school is integrated with some kind of electronic learning environment, like the one that is developed by the company itslearning. There is a lot of competition among companies that develop electronic learning environments. To stay relevant they have to keep constantly distinguishing themselves. One way for them to do this is to keep up with new technologies and to make sure it is compatible with their electronic learning environment.

One of the new technologies that are making a rise in the educational field is virtual reality. Virtual reality (VR) has already been shown to have great benefits to the learning processes of students. Multiple researchers have concluded that using virtual reality in combination with normal lessons will gain student engagement and improve student achievements in class. However, most teachers are not yet convinced of the added benefit of the virtual reality technology. They believe it will take them a lot of time and effort to implement virtual reality into their lessons.

Google, Microsoft and some other big companies have already been trying to develop educational virtual reality content and platforms. Unfortunately, the step for teachers to use this has not yet been made. To make the use of virtual reality more accessible and interesting to teachers, itslearning wants to integrate this new type of technology into their educational platform. In order to do this, they want to make a teacher-friendly user interface in itslearning that integrates virtual reality in such a way that teachers can make guided lessons with the use of premade 3D models, which can be used to teach already existing learning plans and predefined subjects. The main objective of this research was to discover what aspects and features are needed and wanted in a virtual reality tool for teachers where a teacher can make guided lessons with the use of premade 3D models from third parties. This main objective was achieved by making a prototype of a lesson that should be able to be made with such a VR tool. This lesson was made in co-creation with a biology teacher. The sub-questions that had to be answered in order to achieve the main objective were:

1. *How can teachers implement virtual reality in a way that it can help students to get a better understanding of certain subjects?*
2. *Which type of virtual reality programs and tools should be used?*
3. *What is the available 3D content that can be useful in VR on the topic of biology, which can be used for educational purposes?*

4. *What is needed to make a guided virtual reality lesson with voice recordings where teachers are satisfied with the interaction?*
5. *What is the reaction of the teacher to the made virtual reality lesson?*
6. *What is the reaction to the student interaction with the virtual reality lesson?*

These questions were answered and two prototypes were made. The first was a clickable prototype of the user interface of a virtual reality tool for teachers. This clickable prototype was made in cooperation with a biology teacher of *Bonhoeffer College Bruggertstraat*. This prototype is not the main prototype of this project and only a draft version of this prototype was made. The second and main prototype was made to get more insight into the possible features and necessities of a VR tool for teachers. This prototype is a virtual reality lesson made in co-creation with a biology teacher. The reason for making such a lesson is to identify important components that a teacher would need in a virtual reality tool for teachers to make VR lessons. The prototype of the virtual reality lesson needed a specific educational topic since there was a limited amount of time of 10 weeks available to create the prototypes. The chosen educational topic that was researched is biology. The prototype consists of a lesson in this topic that has been made in collaboration with the biology teacher of *Bonhoeffer College Bruggertstraat*. Furthermore, the VR lesson was tested by students of *Bonhoeffer College Bruggertstraat* and their feedback on the lesson as well as on the concept of having VR lessons in class were investigated.

This report consists of four parts, the first part is an introductory part, this includes a state-of-the-art review about virtual reality tools for teachers. Here recent literature is presented about the topic and an analysis of the current mindset in the field is present. The second part of the research report includes the ideation and specification of the research. The third part of this project is the actualization phase. The Realisation and evaluation are in this part of the research project. The last part of this research project is the concluding phase. The conclusion, discussion, and possible future work are discussed here.

Chapter 2 - State of the art on a virtual reality tool for teachers

The main task of this project is to discover what aspects and features are needed and wanted in a virtual reality tool for teachers where a teacher can make guided VR lessons with the use of premade 3D models from third parties. To understand the current level of development regarding this topic there is a need to explore current research. This will include research into the added benefit of virtual reality in the classroom and an analysis of the virtual reality tool including current research considering a virtual reality tool in education, the use of virtual reality in the classroom and important implementation aspects.

2.1 The added benefit of a virtual reality tool

To inspect what ought to be the added benefit of a virtual reality tool for teachers, the educational benefit for students of using virtual reality was investigated. The need to research this originates from the question: *why is there a need for this proposed product of a teacher-friendly user interface where a teacher can make guided lessons with the use of premade 3D models from third parties?* This question was answered in order to attract potential students, teachers, and schools.

virtual reality in education

The added benefit of using virtual reality in education had been researched throughout different courses and subjects. For this project, the benefit of virtual reality for scientific topics is looked at in combination with the overall benefit of using virtual reality in education.

Virtual reality can help students with their educational achievements due to immersion and motivation. Immersion is the first theme that helps students in their educational achievements. Researchers have concluded that the immersive context given in a virtual reality environment by not giving notice to the feedback source can benefit the learner (Gac, Richard, Papouin, George, & Richard, 2019). This means that when the user does not know how the feedback is received by the program, the student will be more immersed in the virtual environment. An example of how the user would notice the feedback source would be by pushing a button when the user is done reading something. A better solution would then be for the user to not have to push the button because the program notices the eye movement of the user. Additional to “no noticeable feedback source” Lee,

Wong, et al. (as cited in Cheng & Tsai, 2019) state that if students have a strong sense of presence in a virtual reality environment, they are going to be more successful in the learning tasks they can perform or achieve. On the other hand, Innocenti, et al. (2019) considered *engagement* as a reason for immersion, they stated that the engagement of students is gained by the level of immersion that is present in virtual reality and that it promotes learning due to gained interest in the topic. Additionally, engagement is also talked about by Charney, et al. (2007), they state that meaningful engagement of students in the practice of real science can make a difference in their understanding and beliefs. This means that the immersion in virtual reality can make a difference in the understanding of certain topics. Innocenti, et al. (2019) also give another reason why immersion helps students, they describe that virtual reality: “fosters educational experiences that draw on ‘situated learning’ and ‘learning-by-doing’” (p. 103). Learning-by-doing can help the student’s understanding of a certain topic. So the immersion created in virtual reality can help a student understanding something, and therefore can help their educational achievements.

Additional to immersion, motivation is also considered to be a central theme as to why virtual reality in education can improve student achievement. Stepan et al., (2017) state that virtual reality in education may improve knowledge retention and can increase study motivation. They compared virtual reality with the regular way of teaching and found that the students who used virtual reality gave higher grades to some subjective measurements including engagement, enjoyment, usefulness, and learner motivation. Furthermore, Gomes et al. (2019) state that learning motivation is a critical measurement of the effectiveness of virtual reality as a learning tool. Conjointly, Amrein and Berliner (2002), divulge in the dependency of motivation when it comes to learning achievements.

As a consequence of immersion and motivation as central themes as to why virtual reality can help students with their educational achievements, Merchant et al. (2012) convey that using virtual reality in education creates a positive relationship between the spatial orientation virtual reality gives, the self-efficacy of a student and the students’ performance on a chemistry learning test. The ability of spatial orientation permits students to imagine simple or rigid transformations of an object by mentally rotating it in their minds (Ekstrom, et al. as cited in Merchant, et al. 2012). As an example, Merchant et al. (2012) give that students should be able to rotate a molecule while studying bond angles of molecular structures. They also state that the learner’s sense of presence in the environment is connected with the learner’s spatial orientation. Their research affirms that the ability of a student to explore, manipulate, move and rotate objects in a virtual environment is related to the self-efficacy of a student in learning about the object.

In conclusion, the main themes that are considered when researching why virtual reality can help students with their education are the immersion that is created and the motivation that is gained from the experience. Consequently, it is stated that the spatial orientation in virtual reality creates more self-efficacy of a student in learning about an object.

2.2 The virtual reality implementation tool

To explore what the virtual reality tool should and could entail, similar existing work was investigated, similar existing research was found and analyzed, and information on the implementation of the virtual reality tool was found in order to get the full benefit for the user.

Similar existing work

To understand what has already been made existing work similar to a virtual reality tool for teachers as discussed in this research was investigated. There are four companies with similar products.

The first company that was researched was Google. Google has tried to come up with a similar kind of concept, Google Expeditions. This entails a set of available 3D environments where students can see the environment through virtual reality and augmented reality (Google, n.d.). The difference between Google Expeditions and a virtual reality tool for teachers as is discussed in this project is that Google Expeditions does not allow for movement throughout the VR environments. Additionally, the available environments, interactions, and questions are preexisting and do not allow for personalization. Therefore, these environments also have no need for a teacher since they have already been fully developed and do not give any feedback after an expedition has taken place.

Additionally, Microsoft also has a multitude of virtual reality products that can be used in the classroom. They have something called Mixed Reality for education, which can be used in combination with other applications including mobile or computer applications which include content and lessons (Microsoft, n.d.). Because of the fact that the content, including the lesson, has already been made, the added role of the teacher is smaller than in the virtual reality tool for teachers that this project will strive to make. Subsequently, Microsoft also offers a way for people to draw in 3D in a simple manner that requires no special training (Microsoft Education, n.d.). This feature does offer freedom for teachers to design the content. However, this feature is not integrated with a tool to view this content in virtual reality and to be able to move or receive some kind of feedback.

Furthermore, another existing company that uses virtual reality in classrooms is ClassVR. ClassVR made a product that allows the teacher to search for educational content within their database. Additionally, they allow the teacher to add new VR environments or 360 photos and videos (ClassVR, n.d.). Comparing to Google and Microsoft, this platform allows for a little more personalization by the teacher. However, similar to Google and Microsoft, this platform does not allow the teacher to change or personalize the lesson by means of altering or adding to the content, for example by adding parameters, direction, information or questions.

Building on the fact that most platforms do not allow for customization like quizzes, questions, and other elements, is Viar360. They do allow for customization in their virtual reality tool. They have an interactive virtual reality tool that is not solely focused on education. With this tool, users can upload 360 photos and videos like ClassVR and Google Expeditions. However, they have some customization options including using audio files and adding questions and quizzed to the environment. They even allow for more customization by offering the maker to use coding possibilities, like adding custom HTML5 (Viar360, 2019). The distinguishable factor between Viar360 and the product this project is researching is the use of actual 3D environments compared to the use of 360 photos and videos in the VR environment. Additionally, the tool of Viar360 is not integrated with an electronic learning environment.

Existing research on the use of VR in the classroom

Research on the overall use of virtual reality in the classroom is important to determine whether or not the use of a virtual reality tool for teachers is a good idea. Therefore, the use of virtual reality in the classroom regarding teaching biology or similar subjects was researched. Three existing pieces of research considering the use of virtual reality in the classroom for exact sciences were specifically similar to this project.

The first relevant research that was found included the use of virtual reality in the field of biology. In this study, airway management skills were taught to nursing students with the use of virtual reality (Samosorn, Gilbert, Bauman, Khine, & Mcgonigle, 2020). This study consisted of giving nursing students a VR airway intervention that consisted of six narrated lessons which taught the students basic airway management skills. This study showed promising results where the participants felt a high level of presence and immersion additional to the high level of knowledge gain that was achieved (Samosorn, Gilbert, Bauman, Khine, & Mcgonigle, 2020). The correlation between this study and the current project is found in the guided lessons with voice-overs and the field of biology. This study

suggests that when a virtual reality lesson is made the right way, the student can gain knowledge and skills.

The second study that showed relevance to this project was about the use of VR in an architectural course. The virtual reality environment that was created allowed students to be in a virtual construction site (Bashabsheh, Alzoubi, & Ali, 2019). The relevance to this study relied on the fact that this study focused on the acceptance of students of the use of VR in combination with educational satisfaction, which directly relates to the motivation of students to use virtual reality, which was discussed previously as being an important aspect in the students' ability to gain knowledge from virtual reality. Additionally, there is a need for a correct analysis of the surroundings regarding architectural courses. This same need for correct analysis of the environment is needed for students to understand certain biology topics. The study concluded that the new VR method of teaching has a good acceptance level in addition to a good level of educational satisfaction. Furthermore, they stated that the traditional way of teaching lacks in the area of enjoyment whereas VR can increase the enjoyment of learning (Bashabsheh, Alzoubi, & Ali, 2019).

The last relevant study investigated chemistry students who were given chemistry lessons in combination with the use of virtual reality (Merchant et al. 2012). This study concluded that scientific achievements can be improved at college level using 3D virtual reality. Additionally, the results of this study seem very promising in the aspect of designing learning environments where 3D virtual reality technologies are used to enhance student performance on a chemistry learning test. The relevance to this project is the field of science that has been investigated in addition to the positive results of the students who participated in this study.

Concluding, relevant studies in similar fields to biology show that the use of virtual reality in the classroom can help students in their achievements. The studies that have been investigated give a positive outlook on the usability of virtual reality lessons.

Existing research on virtual reality tools for teachers

There is a lot of existing research on the use of virtual reality in education. However, research specific to a virtual reality tool is even more helpful. Unfortunately, not much research has been done on tools that help teachers personalize or make virtual reality lessons from scratch. The existing relevant research mainly concerns the surgical field and training for doctors.

In 2019 a study concerning the comprehension of physicians related to learning anatomy and surgical procedures using virtual reality was published. They made a system to

visualize 3D patient-specific models and paved the way for a potential new tool for teaching. Their system was successful in allowing a better comprehension of anatomy compared with medical imaging datasets. The 3D scenes were created from a CT dataset, which made it patient-specific and was converted to an android file, which made it possible to use as an application on your phone without the need for expensive hardware. The virtual reality environment that was created allowed for a better comprehension than radiological imaging. It also showed great potential as a tool for preoperative planning (Vertemati et al., 2019).

Additionally, another research used anatomy with mixed reality. A research project came up with 'Anatomy Studio', this is a collaborative mixed reality tool that can be used by anatomists for virtual dissections. They used tablets with styli in combination with see-through head-mounted displays. This approach used mixed reality instead of virtual reality. The head-mounted displays that were used were see-through (Zorzal et al., 2019), which made it a combination of virtual and augmented reality, that is why it is called mixed reality. Existing issues with 3D reconstruction from anatomical slices, include having ill-suited mouse-based user interfaces designed for single-user interaction. This research suggests that this combination with tablets and mixed reality can be a viable approach to overcome those issues (Zorzal et al., 2019).

Corresponding to the other anatomy related education tools is a new expansion of the 3D technological world, 'virtual surgery'. This new type of 3D technology allows medical students and surgeons to manipulate virtual objects in a way that is similar to actual surgery. (Spicer, & Apuzzo, 2003). One of these virtual surgery tools is 'ImmersiveTouch', a virtual reality personalized surgery tool. This tool lets surgeons simulate procedures to an interactive 3D model that is rendered from CT scans and MRI's (Comeau, 2019). This allows doctors to practice patient-specific procedures and allows students to do the same without actually practicing on a real-life patient.

Concludingly, some tools have been made that allow teachers to use virtual reality in order to teach. However, the form of personalization in these tools does not align with the form of personalization that is achieved by making your own lessons or adjusting lessons, as is the objective of the tool discussed in this research project. The personalization that is mentioned in the existing research mainly focuses on personalizing it for a patient but keeping the overall structure of the program and thus the lesson the same. Therefore, it can be concluded that no significant research for this project has been found in this area.

Important implementation aspects

The main themes where virtual reality can help students with their educational achievements are important when looking into ways of implementation. The different components that are needed for virtual reality to be implemented in a way it helps students in their educational achievements are related to the two central themes, immersion and motivation.

There are many components that can be implemented to achieve a high level of immersion. The first component is the use of high motion-tracked controllers in the classroom when using virtual reality (Siegrist et al. as cited in Crofton, Botinestean, Fenelon & Gallagher, 2019). These motion-tracked controllers would only be useful when the student has a certain factor of control over the virtual reality environment. Additionally, Vogel et al. as cited in Merchant, Goetz, Cifuentes, Keeney-Kennicutt, & Davis (2014) state that if students are in control of their navigation in the virtual learning environment it can have a positive impact on their learning. They also compare this to when the teachers are in control of the navigation in the virtual learning environment. Nevertheless, according to Lee (as cited in Merchant, Goetz, Cifuentes, Keeney-Kennicutt, & Davis, 2014), the students should not be left without any guidance. He said that if some kind of guidance is provided in the virtual reality learning environment, the student performs better than when no guidance is provided. Additionally, an “orientation” process to familiarize the student with the virtual reality environment can help the student when using virtual reality (Christopoulos, Conrad, & Shukla, 2018). It could be argued that this also relates to the feeling of immersion.

The motivation that is gained by virtual reality was another main reason why virtual reality can help students in their educational achievements. Kim, Ke, & Paek (as cited in Cheng & Tsai, 2019) found that the motivational quality of young students regarding their learning activity was improved by virtual reality, regardless of whether they were engaged in game-based or non-game-based virtual reality contexts. Their research suggests that virtual reality itself is the reason for higher motivational levels. Another study also looked into virtual learning environments and the motivational level of students. They found that it is important to keep using updated technology and updated experiences when designing a virtual learning environment, as this would help maintain a high level of motivation (Vergara, Rubio, Lorenzo & Rodríguez, 2019). As a teacher, it would then be necessary to keep updating the environment and to keep up to date with the latest virtual reality technology.

To sum up it can be stated that immersion can be created by using motion-tracked controllers, making an environment where students are in control of their own navigation, making an environment where there is guidance from teachers in the environment and implementing an orientation process that is integrated into the learning path for the student.

Additional to immersion, teachers also can help keep the motivation level high by updating the environment and the used technology.


Chapter 3 - Requirements capture & Ideation

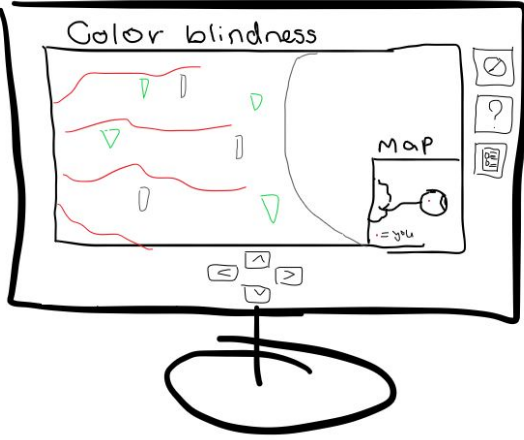

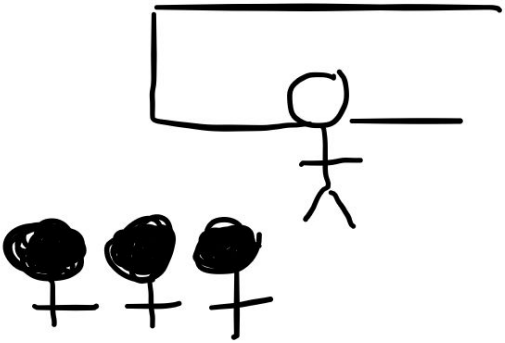
The goal of this chapter was to contrive a number of creative ideas for the virtual reality tool and the virtual reality lesson from which one or more ideas can be used as a starting point for the project. The first part of this chapter will focus on capturing the requirements, this was done with the help of a storyboard, a user story, a user scenario, and requirements. The second part focused on the ideation of both the lesson content and the virtual reality tool.

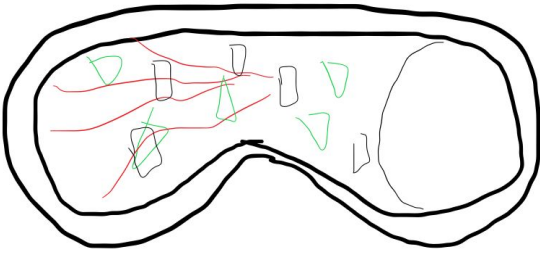
3.1 Storyboard, user story and user scenario

Storyboards, user stories, and user scenarios can be used to identify important aspects and requirements of a system. For this reason, a storyboard of a teacher using a virtual reality tool, a user story about a teacher who would use such a virtual reality tool, and a user scenario where Jane, the teacher, makes a virtual reality lesson using the virtual reality tool has been made.

Storyboard

	<p>A teacher wants to teach students about color blindness. The teacher goes to itslearning's virtual reality search engine and searches "colorblindness". A number of items come up and the teacher clicks on the first, most relevant one: 'color blindness'</p>
---	--

	<p>The teacher is redirected to a new page with the environment. The teacher sees the view of his current position. At the bottom of this view, he also sees the map and his current position on the map. The teacher can turn around by dragging his or her mouse in the environment, and he or she can move by using the arrows of their keyboard or the arrows on the screen. On the right side of the screen, the teacher sees some options like add a question, marked by the question mark button.</p>
	<p>The teacher clicks on the add question button and a new window pops up. The teacher can fill in the question and the answer. (e.g. what in this environment causes people to see color) This question will now be asked in the VR environment when the student is approximately at the same location as the teacher is when making this question.</p>
	<p>Once the lesson starts, the teacher explains that the students are going to learn about color blindness and the teacher gives them all their virtual reality glasses.</p>

	<p>The students put on their virtual reality glasses and look at the environment and walk around to explore.</p> <p>Once they are around the same point where the teacher put in the question. They hear a voice asking them the question. They can answer by clicking on the right object. (e.g. one of the cones)</p>
---	---

User story

As a biology teacher, Jane prepares lessons for her three biology classes with the help of the curriculum and the books that the school provides. Jane teaches the students by giving the lesson and tests the students by asking questions, giving assignments and tests. Jane also needs to check all the tests and assignments she gives the students to get a good overview of the capabilities of each student.

Jane wants to be able to quickly make a lesson in VR that corresponds with the curriculum and the book the school gave her to teach the students about biology. She wants to be able to see their progress and answers to questions and assignments given in the lesson.

User scenario

1. Jane wants to make a lesson
2. Jane does some research into the topic of her lesson and finds that a lot of students have a hard time understanding the subject matter.
3. Jane decides to make the lesson using VR because this seems to help students understand subject matter
4. Jane goes to itslearning to make a lesson in VR
5. Jane searches for pre existing virtual reality environments in the library.
6. Jane finds one she likes that corresponds to her subject.
7. Jane starts with the environment and adds some information in the form of a voice over where she tells her students about the subject.
8. Jane wants to let the students explore in the VR environment to investigate and place all the information she just told them.
9. Jane adds a question for the students concerning the subject matter.
10. Jane adds some more questions and voice overs and saves the VR lesson.
11. Jane uploads the lesson to the VR gear.

12. The next day Jane lets the students do the virtual reality lesson in class and looks at the results of the questions per student to check what issues need more attention in class.

3.2 Requirements

A list of requirements can be used as a starting point for the ideation process. For this reason, such a list has been composed. Since two prototypes were made, a virtual reality tool interface and a virtual reality lesson, two requirements lists were necessary. The two lists were used to show the teacher, who is helping with the project, what requirements there are. The teacher then added, selected and prioritized the requirements using the MoSCoW method.

The virtual reality tool requirements:

- A library with a search function for 3D models so teachers are able to search for a model that can be used in their lesson.
- An environment where the 3D lesson can be made by the teacher. In this environment, the teacher should be able to add questions, information through voice over and/or text, assignments, and interaction. In this environment, the teacher should be able to make certain parts of the 3D environment off-limits to students. Additionally, the teacher should be able to navigate and move inside the 3D environment when making the lesson to get a good understanding of what the students can do and see in the environment.
- An easy and quick way to upload a lesson to the virtual reality gear is required. This should be compatible with the chosen VR gear.
- An environment where the answers of the student in the VR lesson can be viewed by the teacher is needed for the teacher to be able to understand the level of knowledge the students have regarding the subject.
- The whole environment should be easy to use by teachers without any knowledge of VR or 3D modeling.

The virtual reality lesson requirements

- Questions must be presented to students inside the VR lesson.
- The students must be able to look around freely to make the lesson as realistic as possible.

- Some form of interaction should be present in the lesson, examples of this are being able to interact with objects by moving them or being able to click on them and have something happen. The reason for this is to make the lesson more active instead of passive.
- A variety of text, sounds, and assignments with interaction should be present in the lesson and be presented to the student.
- The lesson should be compatible with the chosen VR device.
 - This includes that the way of controlling the environment must be compatible with the controller of the device.

MoSCoW method

Before the ideation could take place it was necessary to identify the needs of the user of the virtual reality tool for teachers. For that reason, the teacher was asked to come up with a sorted list of requirements with the help of the MoSCoW method. The MoSCoW method is a prioritization technique that can be used to identify the most important and least important aspects of a product to a person ("What Is MoSCoW Prioritization?" n.d.). MoSCoW is an acronym that stands for the four different categories of priority: Must-have, Should-have, Could-have, Will-not-have (Madsen, S. 2020). Two subclasses have been made to separate the requirements of the two prototypes.

The first subclass is for the teacher interface of the virtual reality tool. In table 1 the answers of the teacher to the MoSCoW method are presented

	<i>First item</i>	<i>Second item</i>	<i>Third item</i>
Must have	Ability to move inside a 3D model	Ability to insert questions	Ability to give information, using voice over or text
Should have	A means of inserting an assignment	Ability to see the students answers or results of the questions and assignments	A library for 3D models/environments
Could have	A way to insert interaction for the students with the environment	Ability to exclude an area of a 3D model when necessary	
Will not have			

table 1: MoSCoW method for the teacher interface of the virtual reality tool

One requirement that has been drafted previously is not incorporated by the teacher in the MoSCoW method ‘An easy and quick way to upload a lesson to the virtual reality gear is required. This should be compatible with the chosen VR gear.’, the reason for this is that this is not the teacher’s area of expertise and should therefore not be classified by the teacher, however, this requirement is still necessary.

The second subclass is the lesson that is going to be made in co-creation with the teacher. The MoSCoW method for the lesson is shown in table 2.

	<i>First item</i>	<i>Second item</i>	<i>Third item</i>
Must have	Questions for students	The ability for students to walk or look around	Information, animations, visuals must be correct
Should have	Interaction for the student with the environment	Freedom for students to walk around	A variety of text, sound, and assignments with interaction
Could have	The ability for students to look around and think of what every part of the environment is	The ability for students to tinker with the environment	
Will not have			

table 2: MoSCoW method for the virtual reality lesson

The requirement ‘The lesson should be compatible with the chosen VR device.’ is not in this MoSCoW analysis however this requirement is a must-have since the lesson won’t work otherwise. This requirement is not put there by the teacher and therefore is not seen in the teacher’s analysis. New requirements added by the teacher are the ability/freedom for students to walk around, information, animations, and visuals must be correct, the ability for students to look around and think of what every part of the environment is, and the ability for students to tinker with the environment. These new requirements will all be incorporated into the requirements of this prototype.

3.3 Practical requirements

The type of virtual reality tools that are used in a project can have a big influence on how the project is received by its users. An example of this would be when a small simple project has

been made and the VR equipment is very complicated it could seem like a waste of time for the user to get to know the equipment for such a simple project. Not only complicated equipment can influence a project. The use of equipment with bad quality can also negatively influence the project. For this reason, it is important to choose the right virtual reality tools that align with the needs of this project and its users. The question that was asked and answered in this chapter is which type of virtual reality programs and tools should be used for this project. To answer this question there was looked at what VR tools similar projects and product use, the needs of such tools and programs for this specific project and the different possibilities for this project.

The hardware requirements of similar virtual reality lesson products can give a good insight into what is important to have in this specific area. There are a number of similar products that each use different types of hardware, three very similar products and brands with all different approaches to the hardware were investigated.

The first similar product is ClassVR, this company was also discussed in the introduction of this research project. This company has made a headset to use during their virtual reality lessons. The ClassVR's headset does not require any additional devices, like mobile phones (ClassVR, n.d.). Which they state makes it easy to use and reliable. Other aspects that are mentioned about this device is that it can be used hands-free and can be worn with glasses. (ClassVR, n.d.). The website also talks about the affordability of this product. However, the price is not specified anywhere on the website. The control of the virtual reality can be done with the hands of the user, no controllers needed, as long as the hand is approximately 30 centimeters in front of the headset. They specify this as a simple way of controlling an environment without having to search for buttons.

In contrast to ClassVR, Google Expeditions does use mobile phones as a device to look at virtual reality. They use the Google Cardboard in combination with the Google Expeditions application on the smartphone of the user as the hardware to see the virtual reality environment (Google for Education, n.d.). They specify that they do this to make a user-friendly and affordable way to experience virtual reality on every mobile device. This allows for freedom in where and when to use it, as well as freedom of movement. The google cardboards are not only made from cardboard anymore. There is a wide variety of products, made from all sorts of material and ranging in price from 5,07 to 62,26 euros available in the google cardboard shop online (Google VR, n.d.). There is no controller needed except form the mobile device itself, which acts as a controller by moving and looking at things.

Unlike ClassVR and Google Expeditions, Lenovo is a company that does not have its own product to use VR in the classroom. Nevertheless, this brand has made a virtual reality headset that uses other services like Google Expeditions, the Daydream OS store and Wild immersion (Lenovo, n.d.). These services deliver the content while Lenovo delivers the device. Their VR headset, like ClassVR, does not need any other device, and therefore cables, to run. They do however have a controller for interactivity. (Lenovo, n.d.)

In conclusion, it can be stated that mobility, freedom in movement and affordability are important aspects that similar products have kept in mind while developing implementations for virtual reality in the classroom.

The needs of this project can differ from the needs of similar products, therefore it is important to also look at the needs in hardware and software specific to this project. The needs of this project in VR equipment can be divided by hardware needs and software needs.

The specific features that the hardware that is used in this project must-have, depend on what needs to be done with it. Since the project's prototype will be used to give lessons to students in a classroom, the hardware should be transportable to the school. It should also be easy to use for students who have never used virtual reality before since everybody should be able to use it. Another must is that students should be able to interact with the virtual environment since this was one of the teacher's requests as well as one of the researched reasons for the benefits of virtual reality in the student's understanding of the subject matter. Therefore there needs to be some form of controller available for the hardware. Furthermore, there needs to be a certain level of freedom in where the student can be placed, since multiple students should be able to go in the environment at once, preferably a whole class at the same time. This means that the hardware should not have to be connected to anything or have a need to be in a specific space.

In terms of software specifications, software that is pre-existing on the device, to minimize the effort of putting software on every device, is preferred. Furthermore, the software should be able to have a way to communicate with another computer when needed. This feature is important to be able to put new lessons on the device and get the results of lessons that have been on the device. This can be accomplished in terms of bluetooth or an internet connection. Conjointly the software must allow for new content to be put on the device, to introduce new lessons.

To sum up, the needed hardware specifications are transportability, easy usability, all students should be able to use it, available interaction by means of a controller and freedom

in placement and mobility. The needed software features are that it is already on the device, communication by means of bluetooth or internet and a possibility to put on new content.

Now that the specifications for the hardware and software of the virtual reality device are clear, the different possibilities that conform to these specifications can be investigated. The different VR devices can be categorized into three categories, phone-based, computer-based, and standalone VR devices.

The first category is phone-based virtual reality devices, this category consists of head-mounted displays that require a mobile phone for use. These VR devices can be used in combination with an application on a smartphone and the virtual reality device itself. (Lee, 2019; Teslenko, n.d.) These VR devices can have controllers connected to them and are the easy and affordable versions of virtual reality devices. However since not all phones are compatible with some of the VR devices this would mean students who don't have such phones, or any smartphone, can not use it, or the school would need to buy compatible smartphones in combination with it. A low-end example would be the Google Cardboard that was discussed earlier. Other examples include the Samsung Gear VR and Google Daydream. The Gear has a touchpad on the headset and the Daydream has a separate controller (Google VR, n.d.; Samsung, n.d.), while most low-end devices have no controller. In terms of transportability, easy usability, affordability, freedom in placement and mobility and all the software specifications, it is what this project is looking for. However, in terms of it being usable for all students in combination with having a controller it does not qualify. Since for it to have a controller a higher-end device is needed, which is not compatible with all phones. especially for the students who do not own a smartphone, who then could not use any of the phone-based VR-devices. A possible solution to this could be to purchase a number of compatible smartphones as a school in combination, but this would be at the expense of affordability.

The second category is computer-based VR devices, these devices require a powerful computer to help with the virtual reality. Some examples include the HTC Vive and the Oculus Rift (Teslenko, n.d.). These computer-based VR devices are not cheap and require a good, and therefore a bit pricier computer. This category does not meet all the requirements that were set. It is not easily transportable since a computer should be transported with it, is not affordable, there is not much freedom in placement and mobility since it is hooked up to a computer, and the software on the device is not standalone and needs a computer. All these reasons make this category of virtual reality devices unsuitable.

The third and last category is standalone VR devices, these devices do not need any other device to function, like a computer or phone. Some examples of such devices are HTC Focus and Oculus Go (Teslenko, n.d.). These sorts of devices come with a range of different kinds of controllers, from very simple to more immersive controllers like gloves. These kinds of devices have no need to be hooked up to wires and are easy in transport and have freedom in placement and mobility. They are easy to use and all students should be able to use it. Also the software features concerning the software already being on the device, a possibility for communication to other computers and the ability to put new content on are possible. This category has different levels of affordability depending on the quality of the processor, the resolution and the controllers. An affordable device with an uncomplicated controller is the Oculus Go, which as the name suggests, is easy to transport, and very mobile.

Overall it can be said that the standalone virtual reality devices meet all the requirements, that the mobile-based VR devices meet most of the expectations but not all and the computer-based virtual reality devices meet the least of the expectations.

In conclusion, the best virtual reality tool for this project would be a standalone VR device like an Oculus Go. The reason for this is that it meets all the requirements that were set in the second part of this chapter. Moreover, a standalone VR device resembles and includes the important aspects that similar companies and products use. More research could be done to make a better distinction between the different standalone virtual reality devices to figure out which is the best and most affordable one and which is best suited for use in the classroom. This research could also include the differences in controllers and their relation to immersion. However for the purposes of this project that is not necessary, and would be going into too much detail. Other research could also be done into comparing more different similar companies and their hardware since two of the companies that were discussed in this chapter made their own VR device. The reasons why they did not simply use an already existing VR device remain unclear. However, making a completely new VR device is not a possibility for this project and therefore was not researched further.

3.4 Lesson content ideation and evaluation

A teacher who was asked to suggest content or lessons that she would like to teach in the virtual reality environment came up with a few suggestions. These suggestions included showing certain processes, like glucose control, showing a certain aspect, e.g. genetic aspects, on multiple levels where it would start at an organizational level and go deeper into

the different levels until the cellular level, explain DNA replication, transcription, and translation, look at the heart and the blood flow through the whole body and show the defense system of a person.

Besides the teacher's content ideas other ideas were also explored. These ideas were the result of looking into the class material of biology in high school. The workings of the eye and anatomy were two of the topics that came to mind. These topics seemed both simple to find 3D models of as well as having an added benefit when teaching this topic in virtual reality, by reason of both topics being invisible from outside a body.

To concentrate on which subject within biology the prototype should be used for, an answer to the subquestion *'What is the available 3D content that can be useful in virtual reality on the topic of biology, which can be used for educational purposes?'* is necessary. The research that has been done considering this question focuses on the different topic possibilities in combination with available 3D models.

Not all of the topics that are discussed above, were researched, a selection has been made by looking at the feasibility of making a VR environment concerning each topic. The three most feasible topics were the eye, the heart, and DNA. Considering those topics needed the least number of 3D models, which made the implementation more feasible. For each of these three topics the question that needs to be answered is: *Is the available 3D content for this topic, useful in the topic of biology, to be used for educational purposes?.*

The eye

The first topic that was considered was the explanation of the function of an eye. The usefulness of the available 3D content regarding the eye can only be determined by following three steps. The first step is knowing the minimum requirements for such a 3D model when used in biology for educational purposes. The second step is to find and research models that meet the minimum requirements. The last step is to consult with a teacher to determine the educational benefit of using this topic.

To discover the minimal requirements of a 3D model for the eye there should be looked at possible lessons that would need the 3D model. The learning objectives of such possible lessons can be *being able to identify components that make up the eye* or *understanding the causes of color blindness*. Another lesson could include the journey of the development of an image, from the eye to the brain. This would explain how a real-life image gets transformed into an image in your head, via your eye. The minimal requirements for a 3D model where students are able to identify components that make up the eye and which lets students understand the causes of color blindness are:

- It should have an outside and inside view
- The eye should show the sclera, the cornea, the pupil, the iris, the lens, (vitreous humor), the retina, the rods and cones and the optic nerve ("Understanding The Structure Of The Eye," 2019).
- The 3D model should be modifiable to make it possible to add new forms and models to the existing model when it does not comply with all the needed components.

From all the models that are available the four models with the most potential were investigated further. All of the 3D models of the eye include an inside and an outside view. Most models have a lot of different aspects that are shown. Components that are not present in the 3D model should be made and added to the existing model if this is possible. The first 3D model is a realistic model of the human eye which includes inside details and six different layers of the eye. The model could give clearance on the topic of layers in the eye since all the different layers can be separated easily. However all these layers are only half of an eye, but by copying the half a whole one could be made. This model is made by the company AVRspot (AVRspot pro follow, 2018) and can be seen in figure 1. The second 3D model includes half of an eye and part of the vessel's muscles and other parts at the back of the eye. The outside half of the eye and the inside of the eye are schematically made instead of realistically. This model is made by MotionCow (MotionCow, 2016) and can be seen in figure 2. The third 3D model of an eye is a very schematically drawn eye which includes multiple models that can be separated. The ability to separate the different layers could be beneficial to show and explain different parts of the eye. This model can be seen in figure 3 and can be bought at cgtrader.com (Babcock1976, n.d.). The fourth 3D model is a very realistic half of an eye, seen in figure 4. This eye has a lot of detail and is anatomically and visually correct. It consists of many distinguishable parts. This model also includes some muscles and the skin connected to and hair of eyelashes. This model shows the 3 different distinct layers of the eye which are the sclera, the choroid, and the retina. Additionally, the lens and its suspensory ligaments can be seen as well. This model is designed and made by Ebers. (Ebers, 2018)

As a third step, a teacher was consulted to check if this topic would be educationally beneficial to explain using a 3D model. However, when asking the teacher for some feedback on this topic it became clear that the eye is not a big part of the subject matter for her students. Furthermore, the explanation of this is not something the students struggle with. Therefore the explanation using 3D models in virtual reality would not be specifically beneficial.

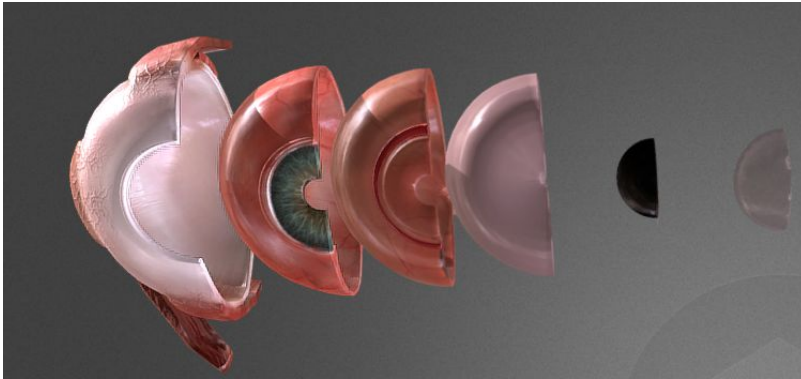


Figure 1: 3D model of half of the eye with different layers. Reprinted from “Human Eye”, by AVRspot. 2018 (<https://sketchfab.com/3d-models/human-eye-160c3a0121784ca8a376eac6b55cc56f>).

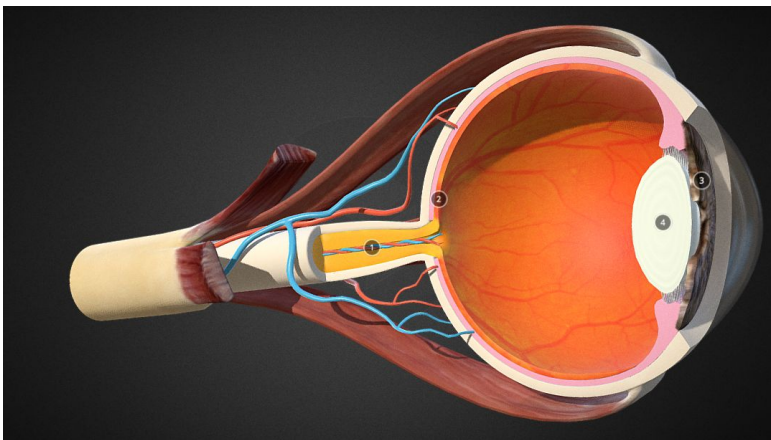


Figure 2: 3D model of half of the eye including vessels and muscles. Reprinted from “Eye Anatomy”, by MotionCow. 2019 (<https://sketchfab.com/3d-models/eye-anatomy-5dac474887174eb78cb7ffce6bd9ce3a>).

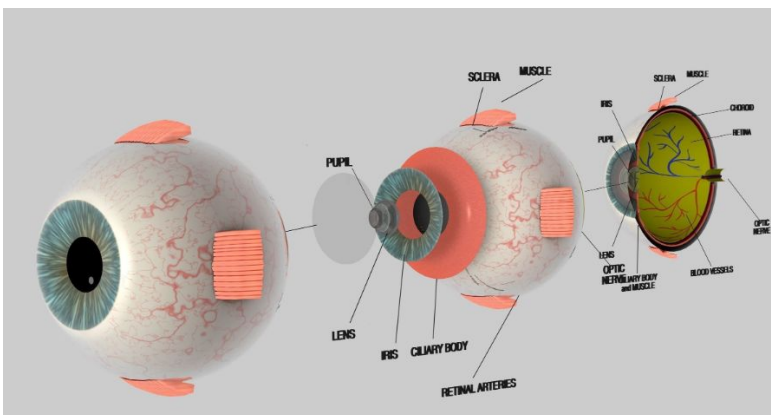


Figure 3: 3D model of the eye with different layers, an outside view, and an inside view of the eye. Reprinted from “Human Eye Cross Section Eyeball: 3D model”, by Babcock1976. N.d. (<https://www.cgtrader.com/3d-models/character/anatomy/human-eye-cross-section-eyeball>).

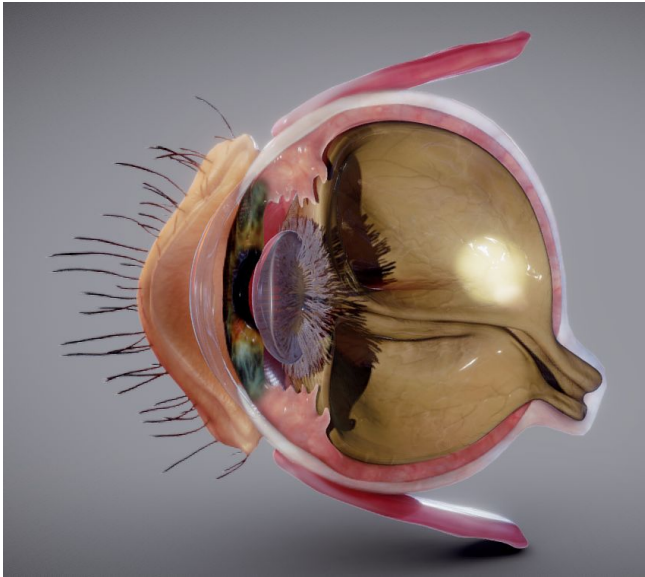


Figure 4: 3D model of the half of an eye, realistically made. Reprinted from “Eye Cross section”, by Ebers. 2018 (<https://sketchfab.com/3d-models/eye-cross-section-181bf8e16a8c4ff9bfb6af07ea6c7ff4>)

The heart

The second topic that was considered is the heart, more specifically the blood flow through the heart. To determine if the available 3D content of the heart is useful in the topic of biology, two steps can be followed. The first step is knowing the minimum requirements for such a 3D model when used in biology for educational purposes. The second step is to find 3D models that meet the minimum requirements and research them. The heart is a topic that was asked by the teacher to look into. That means that unlike the previously researched topic, the eye, this topic does not need a consult of the teacher to check the educational benefit of explaining this topic with the help of 3D models.

The minimum requirements of a 3D model for the heart are dependent on the content that the teacher would like to show. The teacher specified that it was preferred to show not only the blood flow through the heart but also the blood flow through the complete human body where the heart would be the central point. A specific element that was discussed here was to show how an O_2 molecule would be transformed into CO_2 . This, however, was not a requirement but more of a feature that would be nice to have. The basic qualities of a 3D model to show the complete blood flow would be the heart and the blood vessels through the whole body. The vessels should be anatomically correct and it should be possible to look at the inside of a vessel. Similarly, a 3D model or 3D animation of blood flowing would be a big benefit. If such a model is not found then the model should be modifiable to add the blood.

The second step included the search for such a 3D model which is reasonably priced. During this search, it was discovered that finding such a 3D model was hard and

when found, those models were very expensive. The alternative to a whole body could be to concentrate on the heart and maybe the lungs. The reason for choosing the lungs is because of the O₂ to CO₂ configuration, which connects to the lungs and the blood transport from and to the lungs. The requirements of the 3D environment would then have to change. The new requirement of the 3D model would be that it should have a heart with blood vessels connected to the blood vessels of the lungs. Two of the found 3D models that included the heart and the lungs included the blood vessels of the lungs. One did not include these vessels but did include the lungs itself (E-learning UMCG, 2017). This 3D model can be seen in figure 6. One of the two models that included the blood vessels, seen in figure 5, did not look anatomically correct when looking inside the heart (Ebers, 2018). The one that was the most specific and included a good inside view did not include an inside view into the blood vessels of the lungs. However, there is a good 3D model that has a visualization of the inside of a bloodvessel (Neural Impulse Media, 2016) which can be seen in figure 7. This could be used as a model to simulate the inside through blood vessels instead of using ready models of the lung and heart vessels.

As conclusion, it can be stated that finding a 3D model that fits all the requirements was hard if not impossible. The three models that were found were not optimal. However, there was found an option to go through with making a modified version of a 3D heart model. This option is less optimal. Nevertheless, this option still exists and can be followed through if necessary.

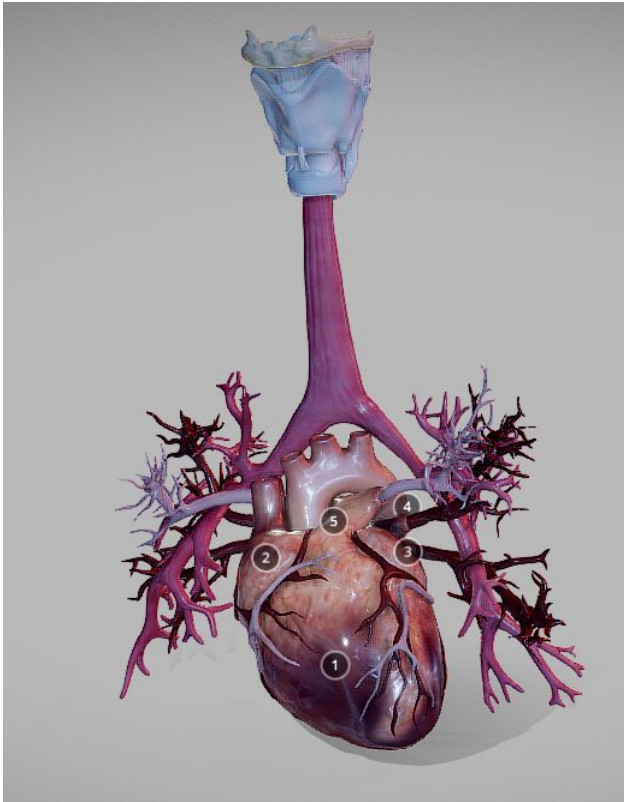


Figure 5: 3D model representing the heart and the blood vessels of the lungs. Reprinted from "Heart Animated And Bronchial Airways", by Ebers. 2018

(<https://sketchfab.com/3d-models/heart-animated-and-bronchial-airways-a0603576a720436cba99c9f958bf0b14>)

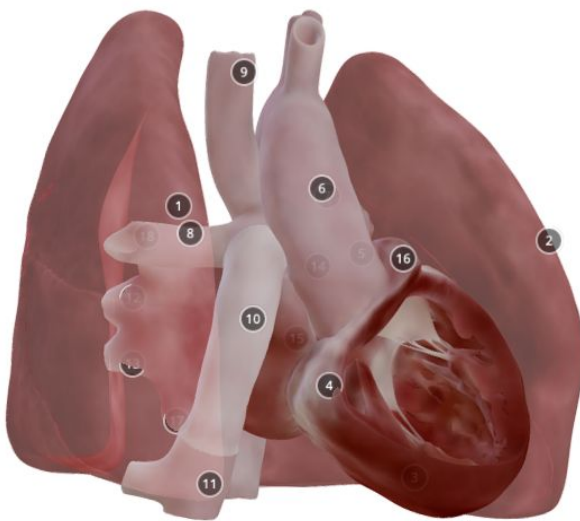


Figure 6: 3D model of the heart and lungs. Reprinted from "Heart after Fontan Procedure", by E-learning UMCG.

2017 (<https://sketchfab.com/3d-models/heart-after-fontan-procedure-5d25e5608a7b4bb2a15ea842cdb5b01d>)

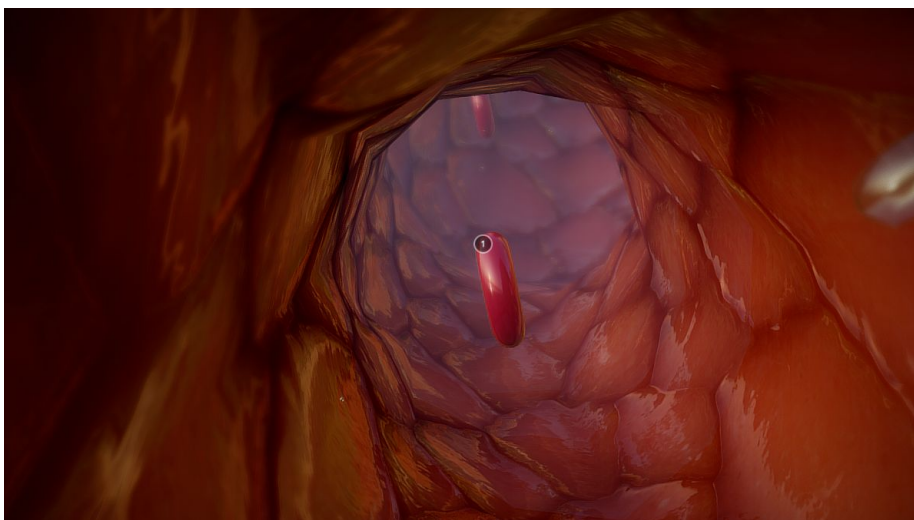


Figure 7: 3D model of the inside of a blood vessel. Reprinted from “Arterial vessel tour”, by Neural Impulse Media. 2016 (<https://sketchfab.com/3d-models/arterial-vessel-tour-246576050a644cb4ae16840922385e39>)

DNA

The third and last topic that was considered was DNA. To determine if the available 3D content of DNA is useful and has educational benefits, the first two steps should be followed again. First knowing the minimum requirements for a 3D model when used in biology for educational purposes, that explains DNA. The second step is to find 3D models that meet the minimal requirements and research these models. Since, like the heart, the topic of DNA was also suggested by the teacher, this topic does not need a consult of the teacher to check the educational benefit of explaining this topic with the help of 3D models. The teacher already explained that since students have some trouble understanding this subject, and a visual environment might help them with this problem.

The first step, knowing the minimal requirements, asks for possible teaching materials concerning DNA. The teacher specifically asked for lessons in either DNA replication, transcription or translation, preferably DNA replication if that was a possibility. DNA replication is the biological process of producing a copy of DNA from one original DNA molecule. (“What Is DNA Replication?,” 2016). Transcription of DNA is the process by which the information in a strand of DNA is copied into a new molecule of messenger RNA (mRNA). (“Transcription / DNA Transcription,” n.d.). DNA Translation is the process by which the genetic code contained within an mRNA molecule is decoded to produce the specific sequence of amino acids in a polypeptide chain. This information is useful when looking at the minimal requirements for the 3D models. The 3D models that are used to explain DNA replication, transcription and translation need to be a DNA strand and/or an mRNA molecule. Since DNA should be able to be separated into two halves of one DNA strand to show

replication and transcription. The DNA strand should distinguish between different bases (GATC and U). To orientate the student there is a need to show a model of a cell with a cell nucleus with the DNA in it. An animation can be self-made for this project since the process is not overly complicated. The models should, therefore, be able to be modified, or include such an animation. However, since DNA is not difficult to model and animate the most important aspect would be the cell and the cell nucleus.

For the second step three models were found that showed a lot of potential to make a combined 3D model that meets all the minimal requirements. Two models were found that showed the cell and the cell nucleus. One of these two models even showed the inside of a cell nucleus (Ebers, 2018). The other model did not show the inside but did show the cell and the cell nucleus (Jimenez, 2016). Another found model was a model of DNA which has visible base pairs. (KageG, 2016). These 3D models are seen in figure 8, 9 and 10 respectively.

Concluding, the topic of DNA has a lot of potential 3D models which are useful in the topic of biology, to be used for educational purposes. Additionally for this topic it is easy to make a model or animation from scratch, due to the easy construction of DNA.

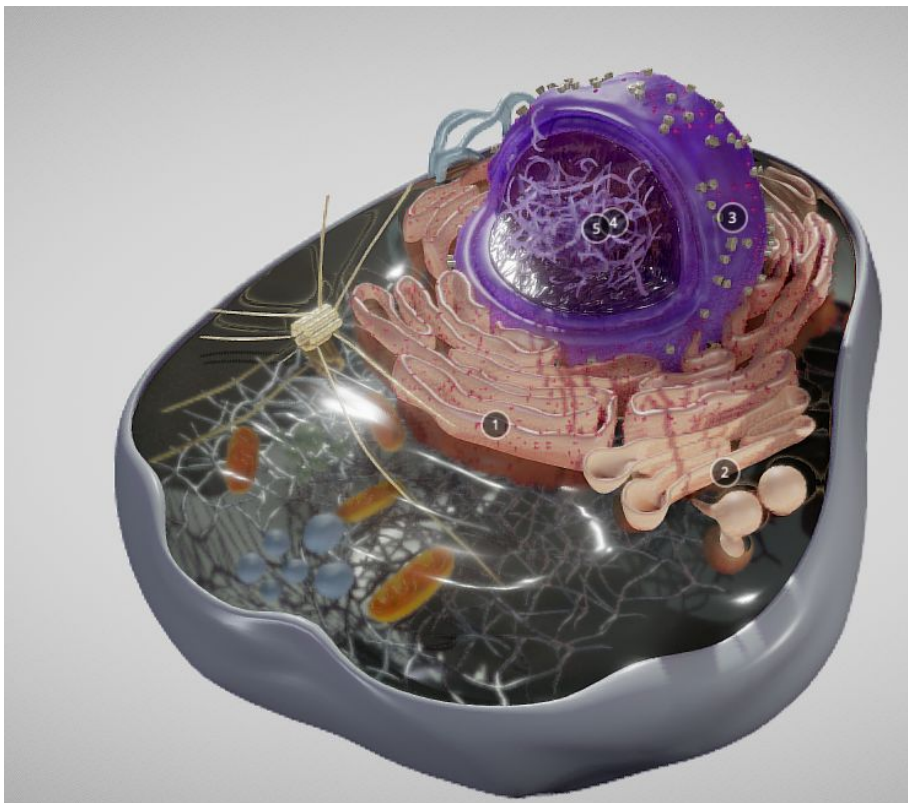


Figure 8: 3D model representing the cell and the cell nucleus, including the inside of the cell nucleus. Reprinted from "Eukaryotic Cell Cross Section", by Ebers. 2018

(<https://sketchfab.com/3d-models/eukaryotic-cell-cross-section-74f714127a8c4211bb1a2cac7195fb1a>).

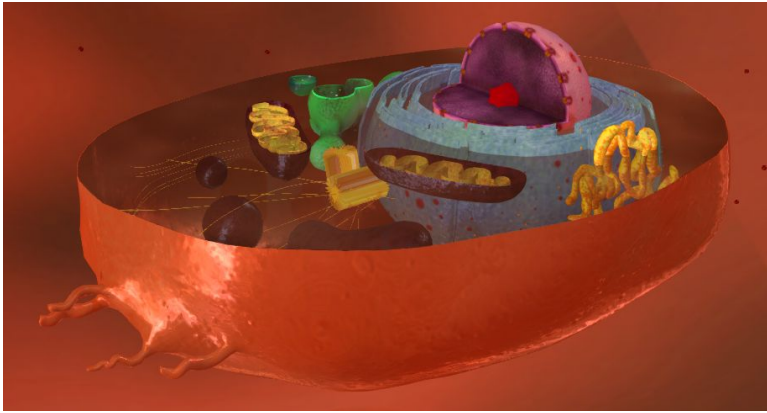


Figure 9: 3D model of the cell and the cell nucleus. Reprinted from “Célula humana”, by O. Jiminez. 2019 (<https://sketchfab.com/3d-models/celula-humana-cdabc716a88d41908d926109ede7aa4d>).

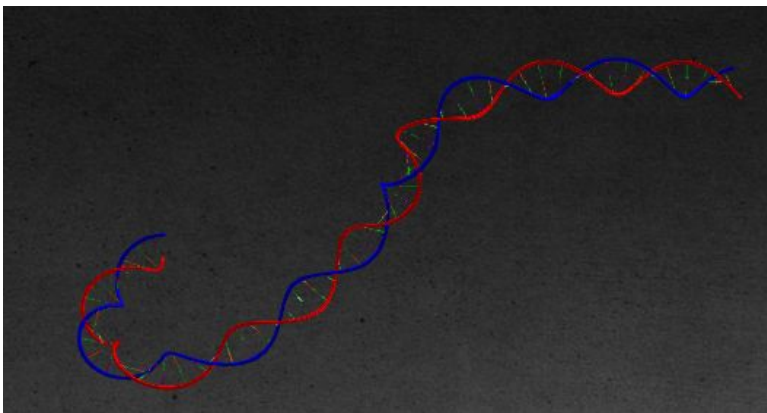


Figure 10: 3D model of DNA. Reprinted from “DNA Animation - Slightly smoother animation”, by KageG. 2016 (<https://sketchfab.com/3d-models/dna-animation-slightly-smoother-animation-11d5d2c5bcf24f0f89b5ea404796f2c4>).

Conclusion

Three possible content topics and corresponding available 3D models were researched in order to answer the question of what the available 3D content that can be useful in VR on the topic of biology is, that can be used for educational purposes. The three content topics that were discussed are the eye, the heart, and DNA. For each of these three topics minimal requirements for corresponding the 3D model were thought up.

The first topic that was researched, the eye, did not comply with the added benefit in education that this project wants to achieve, and therefore has not been chosen to research further. For one of the three topics, the heart, there was not found a model that met all the requirements. However, another specification was made to make it possible to tailor the models to the needs of the lesson. For further research it should be mentioned that there are complete models available of the heart and all the blood vessels in the body, however, they were too expensive for this project. The last topic showed the most potential since it is easier

to model and animate certain things for this topic when needed. This due to DNA being able to be shown schematically instead of having to model something that has to be completely anatomically correct. For this reason, the most promising topic is DNA, and therefore this topic is chosen as the content topic for the virtual reality lesson.

3.5 Ideas for the virtual reality tool

A number of possible ideas and plans were devised and have received feedback from the teacher that is going to be using it. All Ideas were presented to the teacher in the form of an explanation of the idea. The teacher could ask questions regarding the idea but the teacher was not able to test the idea before giving feedback.

The virtual reality interface

The first idea that was thought up was using virtual reality when creating the lesson. This would mean teachers would have to go into the virtual reality to make their VR lessons. The teacher would have to walk around in the virtual reality while implementing certain aspects like questions or explanations on subjects. The teacher would be able to point to a certain place in the virtual reality environment and choose from a list of possible implementable features. These features could include questions, assignments, tests, and explanations. All the implementation can be done inside the VR environment and none is done outside of the environment.

The feedback that was received on this idea by the interviewed teacher came down to it being impractical. The teacher pointed out that looking up information on the subject would be hard to do when they are inside a virtual reality environment. Another possible issue would be that all teachers should have a virtual reality headset at home since many of them prepare their lessons at home. This could potentially be a logistical or financial issue. The overall conclusion the teacher came to was that it would be more practical to prepare the lesson on a computer rather than in a VR environment.

Pre-made lessons

The second idea was about using a library with a search engine that lets teachers search for existing pre-made virtual reality lessons, where the teacher can edit the existing lesson by adding certain features. These features could be the same as talked about in the first idea, questions, assignments, tests, and explanations. A pre-made lesson would include a lesson plan including the needed information and a virtual reality environment including possible interactions that connect to the lesson plan.

The teacher's feedback on this idea was that this would only work if the pre-made lessons were good lessons that have a seamless connection to the subject the teacher wanted to explain to her class.

Existing 3D environments

The third idea that was contrived was to make a library with a search engine which included ready to use 3D environments and models that teachers could use to make their own lesson. The teacher should be able to make the environment from a computer where one of the existing 3D environments could be a starting point. 3D models should be able to be added to the 3D environments when needed. This way the teacher can start with a 3D environment and add the necessary 3D models to complete the lesson. The interface would look like one screen with a few icons which represent certain implementable features like a voice-over, question, test, and assignment. When clicking on one icon the teacher can implement this feature in this location. The teacher should be able to walk around in the environment to explore and implement features. An example of how this idea would look can be seen in figure 11.

The reaction of the teacher to this idea was very positive. The teacher thought this was a good idea and the teacher would like to see it in combination with the pre-made lesson idea. She thought being able to have both choices would be beneficial.

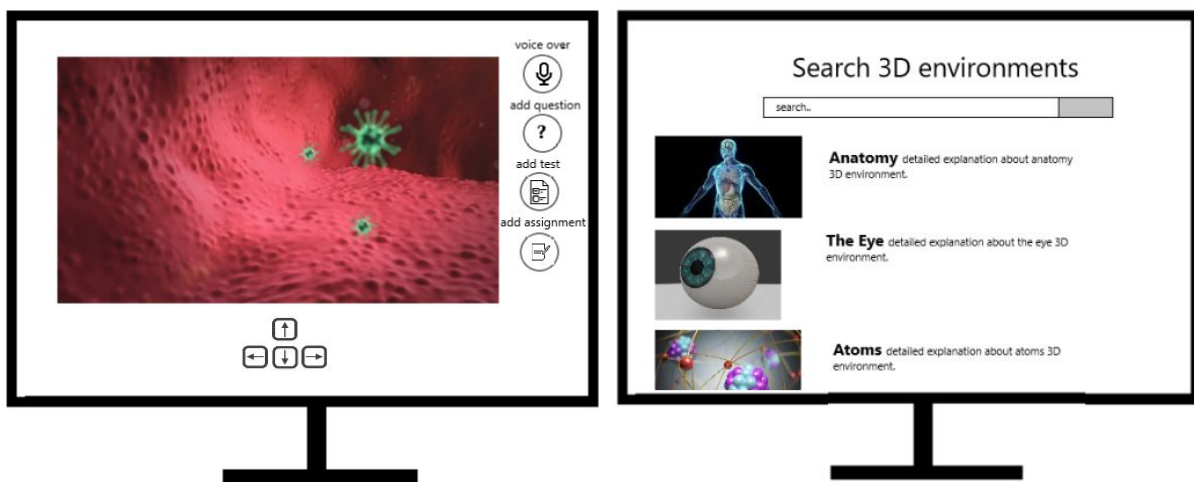


Figure 11: Example of using a 3D environments search library and a 3D environment to make virtual reality lessons.

Real-time virtual reality lesson

Another idea was to present normal lesson sessions inside a virtual reality environment. This would entail the teacher to be inside the virtual reality environment at the same time as the

students, and the lesson to be real-time as well. The teacher can respond to the students and lead them through the virtual reality environment. This whole lesson could be interactive. There would be less need for preparation of the environment itself by implementing questions and such since the teacher can ask the questions during the lesson. A possibility would be for the teacher and the students to be able to see each other, however, this idea would also work if this was not possible but a pointer was shown to the students so the teacher can point to certain areas. A spinoff of this idea is to not make it real-time, thus not interactive.

The feedback of the teacher regarding this idea was that this idea was not preferred by her. The main points that caused this opinion were that the teacher would have to be able to talk about it in a correct manner and order additional to that this would cause the teacher to have almost no overview in the class and over its students. Furthermore, a problem with this idea was that not all students have the same learning pace..

Individual virtual reality lesson

The opposite of the previous idea is to make a lesson that the student does not have to experience in class, but can be used as an extra option for students to delve into the subject matter, or as a homework assignment. This lesson then needs to be completely individual and maybe even has results to show to the teacher. The teacher makes a VR environment with questions and information and the students participate in it in their own time. The possibility of tracking the students' answers and participation is one that could be incorporated into all ideas. And is an interesting addition in multiple applications.

The feedback of the teacher to this idea was quite neutral. The teacher saw this more as a possible option besides using it in the lessons, but not the main functionality.

In closing, the teacher that was consulted was in favor of using the pre-made lesson idea in combination with the existing 3D environments idea. Additionally, the Individual virtual reality lesson was an idea that the teacher could support, however she did not see this as a main functionality. In contrast to these ideas the teacher did not like the real time VR lesson idea and the virtual reality interface idea, both because those would not be practical for her to work in. It should be mentioned that only one teacher was consulted to ask for the opinion on these ideas and that another teacher could completely disagree, this is the reason why further research with multiple teachers could be beneficial. However, the feedback that was given by the teacher has been analysed and especially the feedback on the real time virtual reality lesson idea and the virtual reality interface idea has been agreed on by the designer.

Chapter 4 - Specification

Before the actual lesson could be co-designed, the specifications of the lesson had to be known. These specifications can only be made clear when the basics of DNA replication are known. This chapter will first investigate the knowledge of DNA replication that is needed for the development of lesson content concerning DNA replication. In the last part of this chapter the specifications of such a lesson are revealed.

4.1 Development of lesson content for DNA replication

The content of the virtual lesson has been established to be DNA. But before such a lesson can take place a basic knowledge of DNA is required. The process of DNA replication is one that will be discussed in the virtual reality lesson, but before that can be understood, it is necessary to know the construction of DNA.

DNA consists of two DNA strands that each have a backbone that consists of sugar and phosphate. Connected to each sugar component is a base: adenine, thymine, cytosine, or guanine. between each sugar component is a phosphate component. The two strands are connected at the bases, Cytosine can only be linked with guanine, and adenine can only be connected to thymine. In between the two connected bases are hydrogen bonds to connect them. This whole structure can be seen in figure 12.

Now DNA replication can be explained. DNA replication is the process of DNA replicating itself to make two separate but identical strings of DNA as part of the cell division process. This process starts with the separation of the two DNA strings. This process happens when an enzyme called helicase breaks the hydrogen bonds between two complementary bases. The separation creates a 'Y' shape called a replication fork. The parts of the DNA strings that are separate are used as a source to duplicate the DNA. The duplication of the DNA is done by an enzyme called DNA polymerase, DNA polymerase binds to the strand and then moves along it, adding new complementary nucleotides, which consists out of a base, sugar, and phosphate. On each strand, the DNA polymerase moves in another direction. This causes one end to have multiple DNA polymerases to help duplicate the string since helicase keeps separating a new part. ("What Is DNA Replication?", 2016). A schematic overview of this can be seen in figure 13. When all the base pairs are complete an enzyme called DNA ligase seals the sequences of the DNA into two complete double strands. Then two complete double strands are formed, the two DNA

molecules consisting of the new one and the old one. After the DNA replication, the new DNA strand winds up into a double helix.

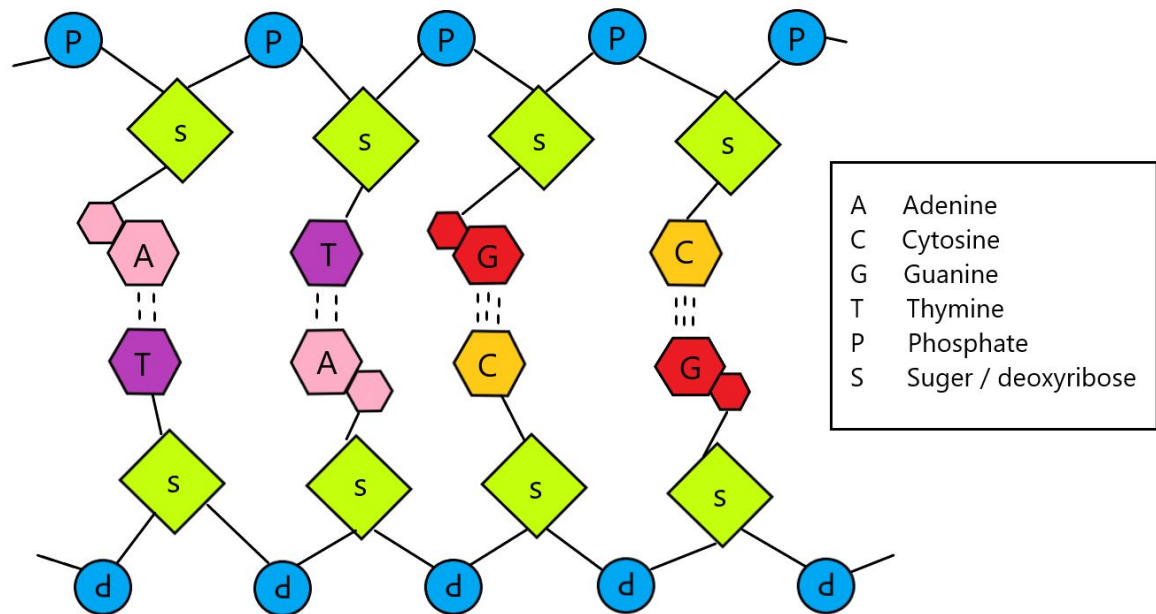


Figure 12: A schematic overview of the composition of DNA.

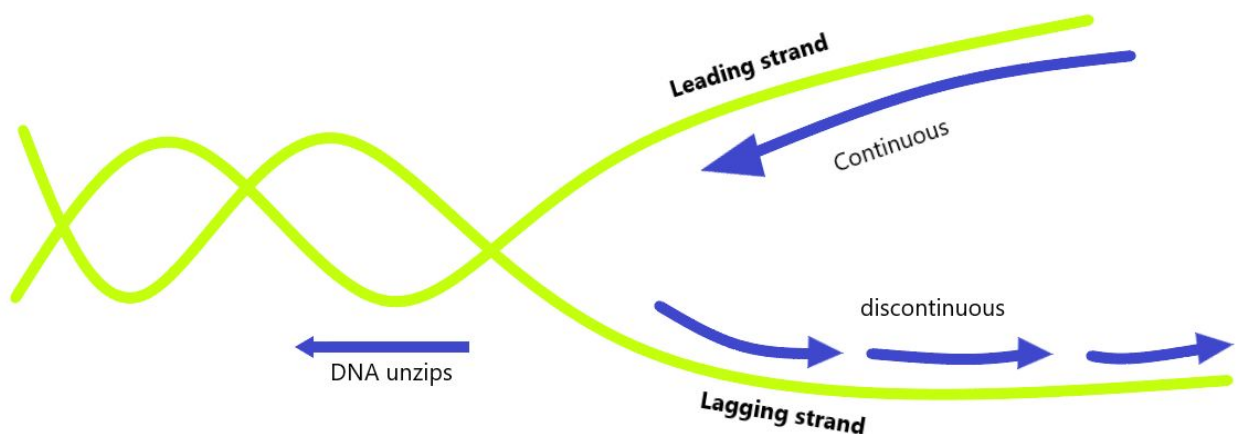


Figure 13: DNA replication fork, illustrates the replication of the leading and lagging strands of DNA.

4.3 lesson specifications

The specifications of the VR lesson as were established by the designer and the teacher are elaborated on below.

The lesson should be made in virtual reality. Additionally, the lesson should be able to be put on the Oculus Go, and be controlled by the Oculus Go controller. The lesson itself should

include a 3D model of the skin. This 3D model should include an animation where the skin is zoomed-in on until only one of the skin cells is seen, then it should zoom in on the inside of the cell nucleus where at least one DNA string should be seen. The DNA string is a 3D model which should include an animation of DNA replication since the teacher specified an animation is needed to be able to show the students the process of DNA replication.

The DNA should be in a helix form and should show the nucleotides, which consist of phosphate, sugar and one of the base, cytosine, adenine, guanine or thymine. The DNA string should show the right base pairs, including their hydrogen bonds. The difference in the number of hydrogen bonds should also be visible, three between guanine and cytosine and two between adenine and thymine. The different bases should be distinguishable by the use of different colors for different bases, or by the use of letters on the bases, e.g. C for cytosine.

The animation on DNA separation should include the separation of the base pairs by helicase. The helicase should be shown as an object that binds around a part of the DNA string and separates the hydrogen bonds. The separate pieces of DNA should then have another object representing DNA polymerase bind around a part of the string and the new complementary nucleotide, that has been wandering inside the cell nucleus, should come to bind to the separated DNA strings, to form new DNA strings. On one of the DNA strings, the DNA polymerase should move in the same direction as the helicase, on the other string the DNA polymerase should move in the opposite direction, which would cause for a need of multiple objects of DNA polymerase on that string, as can be seen in the discontinuous part of figure 13.

Furthermore, in the lesson students should be able to click on certain parts of the DNA model and see the name of this part. These clickable parts should include the sugar, phosphate, adenine, guanine, thymine, cytosine and the freely floating nucleotide inside the cell nucleus. Additionally, text including questions and audio files will be delivered by the teacher on this subject, therefore a way to insert these aspects into the lesson is needed. The questions are all multiple-choice and the answers all need to be clickable. Different courses of action should be possible depending on whether the student answers correctly or incorrectly. This shows the need for different stages, that can occur and lead to new stages.

Chapter 5 - Realisation

As previously discussed in chapter one, this document starts the realization of two prototypes that supplement one another. The first one is clickable prototype of the user interface of the virtual reality tool for teachers. The second prototype is a virtual reality lesson that the teacher would want to be able to create with the first tool.

5.1 The user interface prototype

The user interface prototype is made in cooperation with the teacher who has been giving advice on the whole project. The specifications that have been established in the previous chapter were kept in mind during this designing process.

The design

The overall look of the virtual reality tool should be investigated. Since the virtual reality tool for teachers should be incorporated in the interface of itslearning the user interface of the virtual reality tool for teachers should be based on the overall design of itslearning. The virtual reality tool is made to be a feature that can be accessed within itslearning, for this reason, the access point to the tool should also be made in this prototype. Furthermore, this tool should comply with the overall structure and overview of similar features in itslearning. The most similar feature would be one of the resources like an assignment, test or task since this feature would also be a resource. Figure 14 shows the interface of itslearning when making a new assignment.

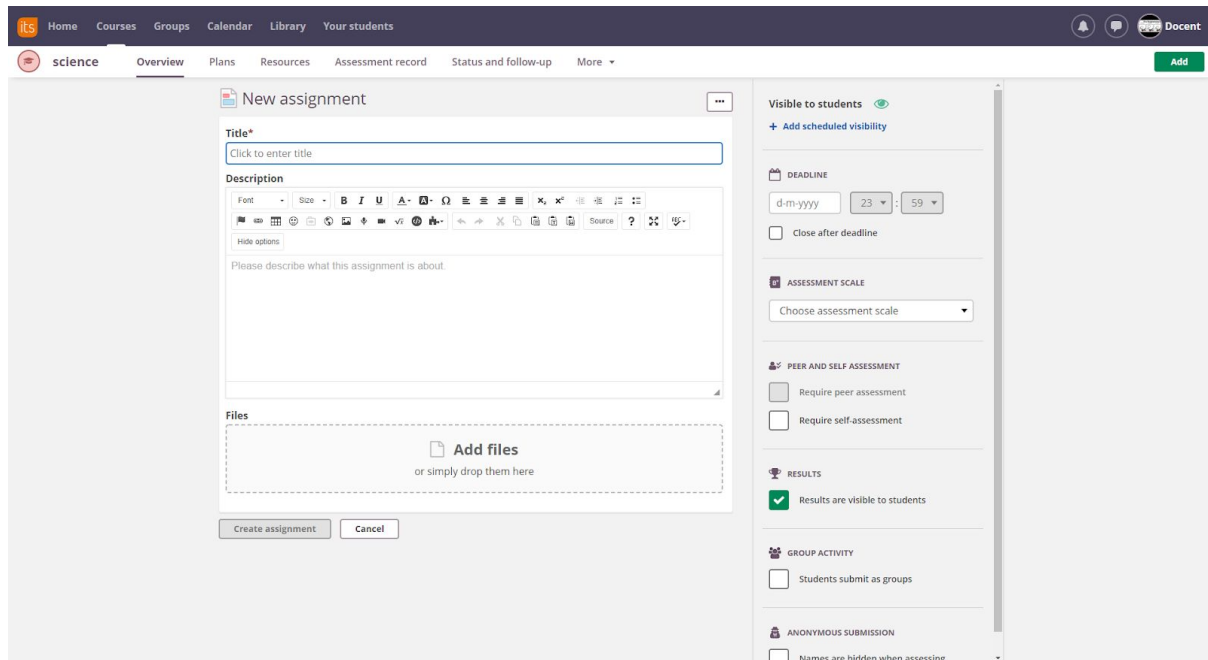


Figure 14: Interface of itslearning when a teacher makes a new assignment.

Additional to the appearance of the prototype, before building the prototype it should be clear what the prototype should be able to do. The global idea of the interface was discussed in the third chapter, the concept that was received positively by the teacher was the idea of using pre-existing 3D environments that the teacher could choose from. Therefore, this idea will be the base of this prototype. Considering the MoSCoW method that was filled in on this subject by the teacher, the different components that are possible to integrate into the prototype can be identified. The must-haves of the interface consisted of three features, the ability to move inside a 3D model, the ability to insert questions, and the ability to give information. Moving inside a 3D model in a clickable prototype will be hard to incorporate in a completely working manner, but a global look at how this can happen can be incorporated. Inserting questions and text or voice-overs should also be possible to show in a clickable prototype. The should-haves and the could-haves: inserting an assignment, seeing student answers, having a 3D model library, inserting student interaction, excluding an area, are less important to incorporate in the prototype but will be kept in mind during the design of the prototype.

The result

The clickable prototype is created in Figma, Figma is a cloud-based design tool that can help with designing and making clickable and usable prototypes. The final prototype was written in dutch for the convenience of the teacher who is dutch. The final result consists of fourteen

screens. All fourteen screens can be seen in figure 15. The screens of the interface prototype can also be seen in appendix 1 through 7.

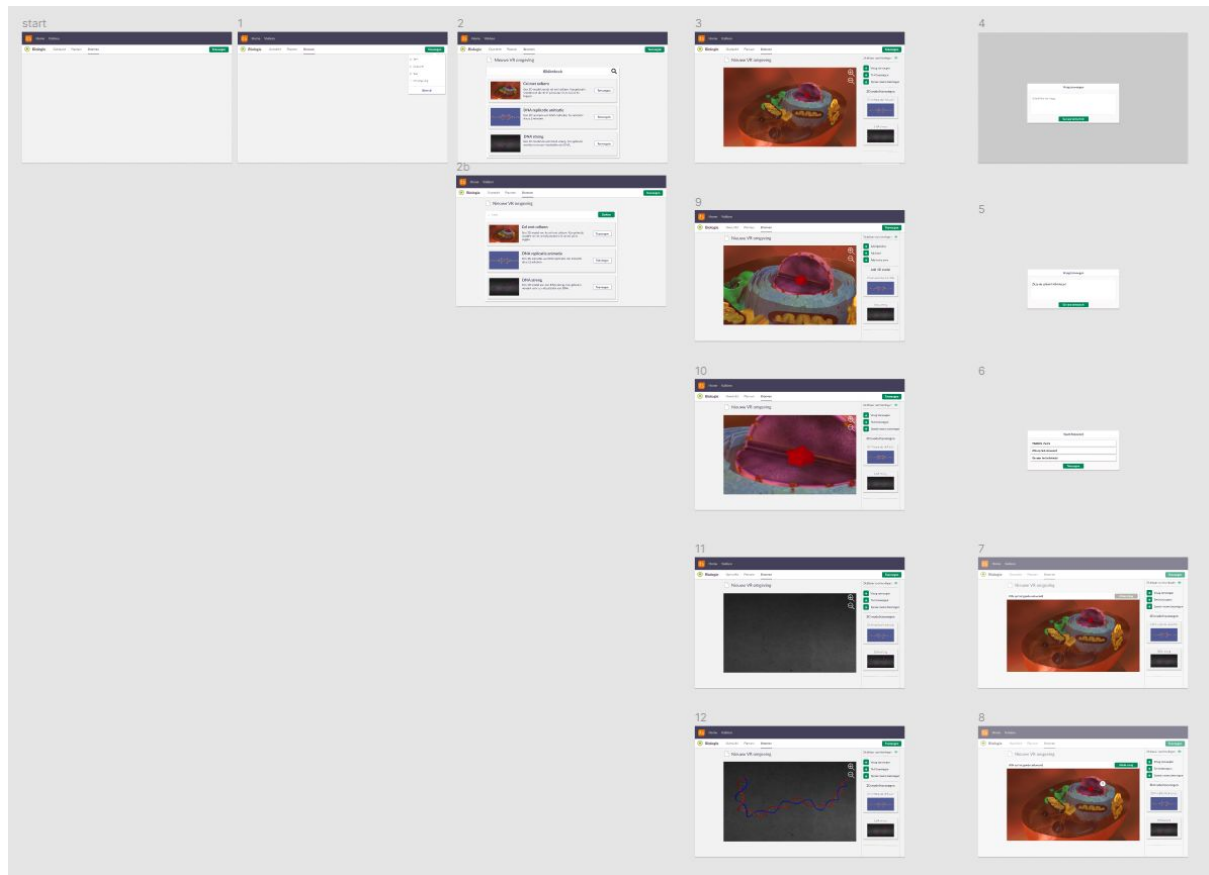


Figure 15: Overview of all screens of the prototype of the user interface

The interaction between the screens can be seen in figure 16, and will also be explained. The explanation will go chronologically. The start screen is a blank screen with the global outline of how the interface of itslearning looks. On this screen, the green button 'toevoegen' can be clicked, which leads to the next screen, screen number 1. In screen number one a drop-down menu was added, it shows the different resources that itslearning offers including a VR environment option. When the VR environment option 'VR omgeving' is clicked on, screen 2 is shown, this screen shows a library with different VR environments that already exist. Screen 2b shows the same library with a search function. This page is shown when clicking on the search icon on screen 2. Both screen 2 and screen 2b go to screen 3 when the add button is clicked 'toevoegen' of the first option in the list of VR environments. Screen 3 shows a 3D environment in the middle, three options on the upper left, adding a question, adding text and adding a voice-over, and two 3D models underneath a text saying add a 3D model. Screen 3, 9 and 11 can switch between each other by clicking on the magnifying glass with a - or a + to either go deeper into the model or go further out of

the model. Screen 11 can go to screen 12 by clicking on the option of adding the 3D model with the DNA string, the second option under '3D model toevoegen'. Screen 3, 9, 11 and 12 can all go to screen 4 by clicking on the add a question button, 'vraag toevoegen'. Screen 4 brings the option of adding a question, clicking on the popup will get the user to screen 5, which is essentially the same screen but with a question inserted since typing in this prototype is impossible. By clicking on the green button, which says go to the answer in dutch, the user gets screen 6, which shows a popup screen with three options for question types, multiple-choice, click on the answer or go to the answer. The button 'click on the answer', the second button, will direct the user to screen 7, which shows the 3D scene again and says to click on the answer above the 3D scene. When the correct answer is clicked on, which in this case is the cell nucleus, the user gets redirected to screen 8, where the user can see the answer in the form of an exclamation point in a circle, and click on the green button above the 3D environment which says make a question. After the user has clicked on the button, screen 3 is shown again. The flow of the interaction between screens 3 to 12 can also be seen in appendix 8.

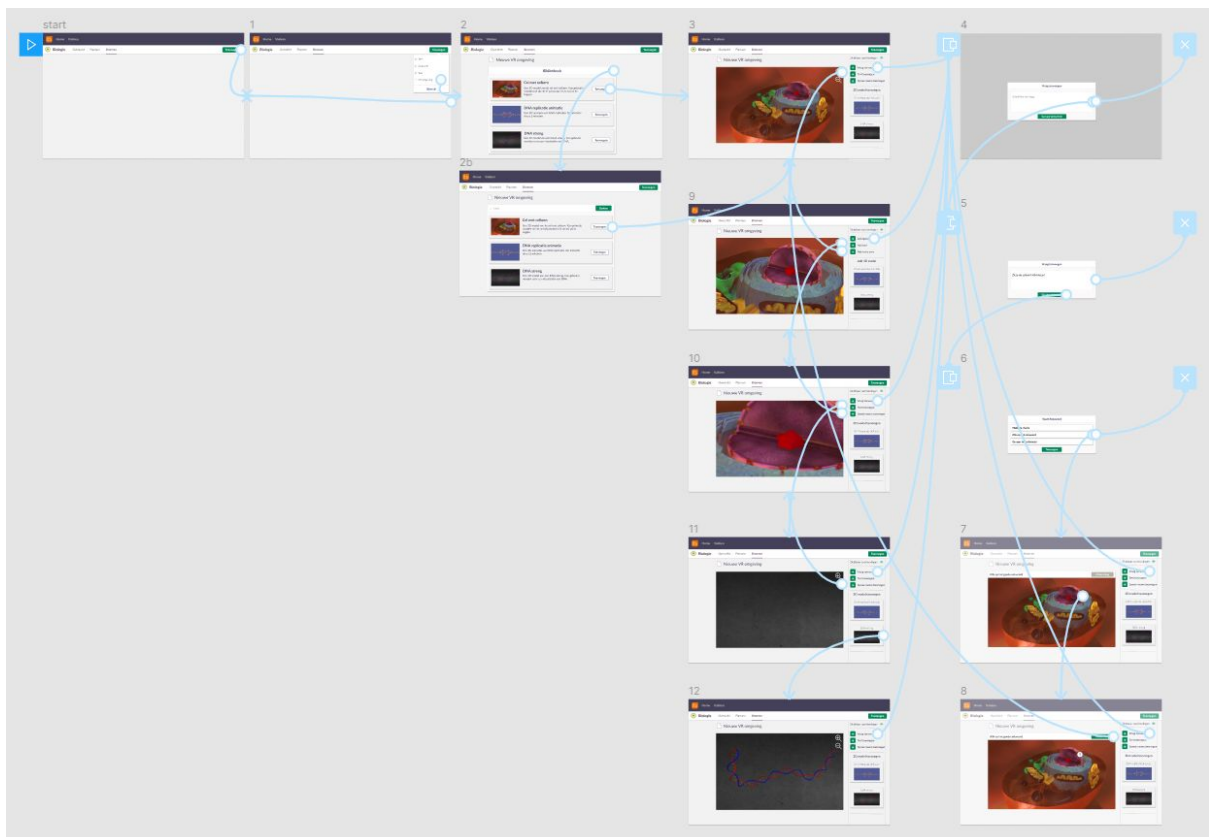


Figure 16: Overview of interaction between screens of the user interface.

The result included the ability to move inside a 3D model in a restricted way, only getting deeper into the 3D model or going further outside of the 3D model was possible in

this prototype. However, more movement would be a valuable option to include in a later stadium. The other must-haves, inserting questions and give information by text or voice-overs were all incorporated by means of the buttons on the right side of the VR environment. The library has been incorporated in screen 2b. The other aspect that was incorporated is a way to insert interaction, by creating the question option for clicking or going to the answer, also this was a means of inserting some sort of simple assignment as well.

The reason for not incorporating having the ability to check the students' answers or results of the questions and assignments was due to this being a whole other interface since this prototype focused more on creating a lesson. The reason for not including the ability to exclude an area of a 3D model when necessary was due to limited movement options inside the environment, which would make restricting harder to incorporate.

5.2 The virtual reality lesson

The virtual reality lesson that was formed in co-creation with the biology teacher will show the process of DNA replication. The process of building and analyzing this lesson consists out of two parts, the lesson plan and the lesson realization.

The teacher's lesson plan

When the animation was finished, a lesson plan was created. The teacher wanted to let the students read the book before taking the VR lesson. In the VR lesson, an introduction in the form of a voice-over should take place first. *"Welcome, you have arrived in the cell nucleus of one of your skin cells. This cell is about to duplicate itself. One cell will become two cells. To do this, the DNA must replicate itself first, this is called DNA replication. I will now run through the process step-by-step."*

After the introduction a question should appear, this question will be *"In which phase of the cell cycle will DNA replication take place?"*, this question will be multiple-choice and the question, as well as the answers, should be shown in the screen. The answers will be G1-phase, S-phase, G2-phase, and M-phase. The correct answer is S-phase, when an incorrect answer is given the correct answer should be shown to the student.

After the question, the teacher wants to give the students some time to look around. The students should then hear a voice-over. *"Look around you, what do you see? By pointing the controller at a specific part you will find out what the name of the part is. What is floating around you? And out of which parts does DNA consist?"*. At this time, the teacher wants the students to point at parts and find out the name of the parts. This form of

interaction should therefore also be in the lesson. This part should either take a specific amount of time or students should be able to indicate when they are finished doing this and want to move on.

After looking around, the teacher wants to ask another question. *“DNA replication starts with disconnecting the connection between the base pairs of a double-stranded DNA molecule. Which molecule is responsible for this?”*. This question again should be a multiple-choice question, with the answers being DNA polymerase, helicase, cytosine, amylase, where the right answer is helicase. When the wrong answer is chosen, the student should hear a voice-over about why this answer is wrong and should be able to choose again. The voice-over for DNA polymerase and amylase is the same, *“This molecule is an enzyme but is responsible for another reaction,”*. The voice-over for the answer cytosine is *“Wrong, this is one of the building blocks of DNA, also called a nucleotide.”*. If the right answer is chosen, the animation will be shown.

After the animation there will be another voice-over, to conclude the lesson. *“That was the DNA replication. The DNA was disconnected by a helicase enzyme and thereafter DNA polymerase put a new DNA string on the already existing DNA strings. Free nucleotides were connected by the enzyme step-by-step. Did you notice something? On the upper DNA string DNA polymerase moves in the same direction as helicase, but on the lower DNA string polymerase moves in the opposite direction. This means that polymerase needs to start over again and again. This is why you get small pieces pasted DNA that still needs to be connected to each other by the enzyme ligase, a kind of Pritt. Watch the animation at least one more time, possibly more often, and write down in your notebook what you have learned about DNA replication and possible questions you still have.”*. After this voice over the user should be able to observe the animation a few more times, either the animation starts to play in an infinite loop until the user has had enough and stops the lesson, or the user can keep choosing an option to show the animation again.

The realization

The realization of the virtual reality lesson on DNA replication included making an animation, making the structure of the lesson and including the actual text and audio in the lesson.

The first thing the teacher made clear was a must, was an animation of DNA strings that separated with the help of the enzyme helicase and DNA polymerase. The requested animation was created with the 3D-modeling and animation program called Maya. Figure 17 shows the model before the animation, figure 18 and figure 19 show the model during the

animation. Apart from the 3D model of DNA, the enzymes, the nucleotides, and its animation, another simple model was produced of a cell. The DNA model was placed in the cell.

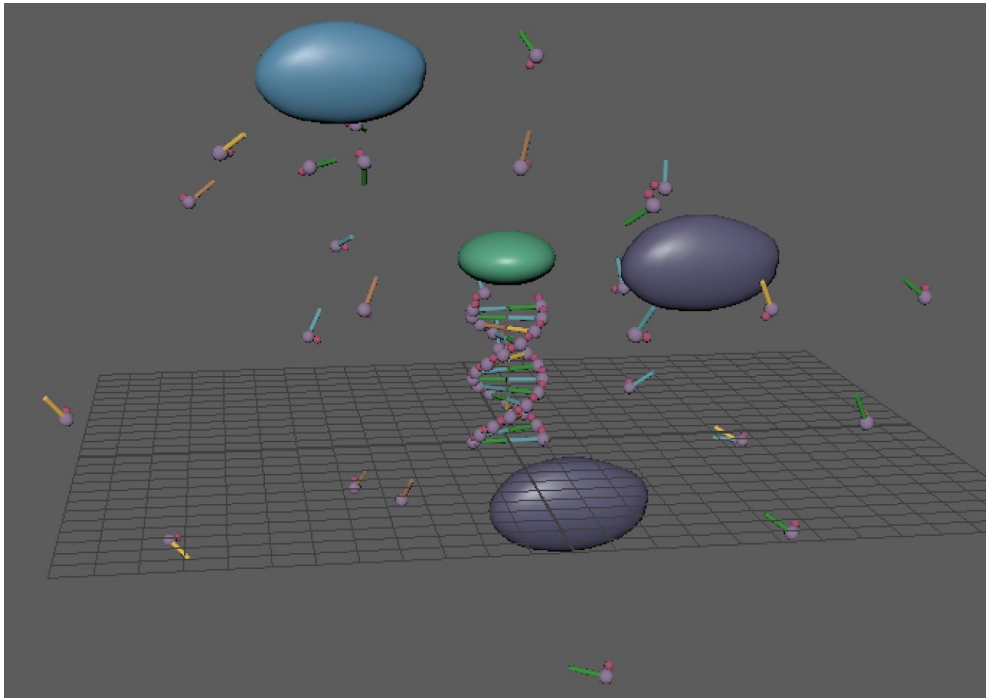


Figure 17 : The DNA separation model before the start of the animation.

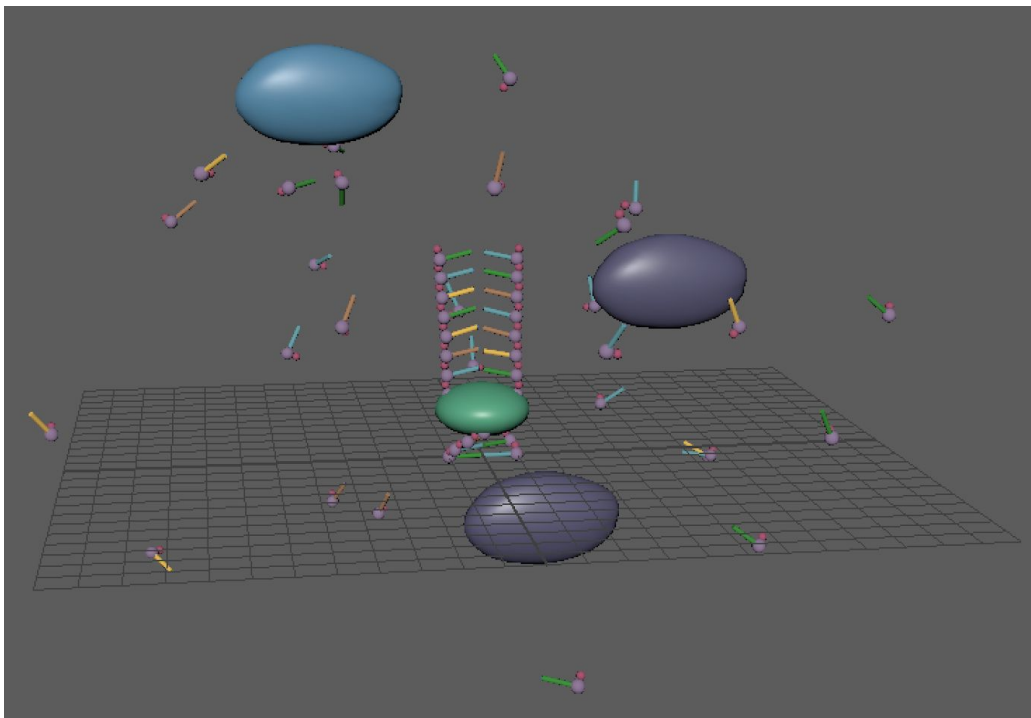


Figure 18: The DNA separation model during the animation process in which the two DNA strings are separated by the enzyme helicase.

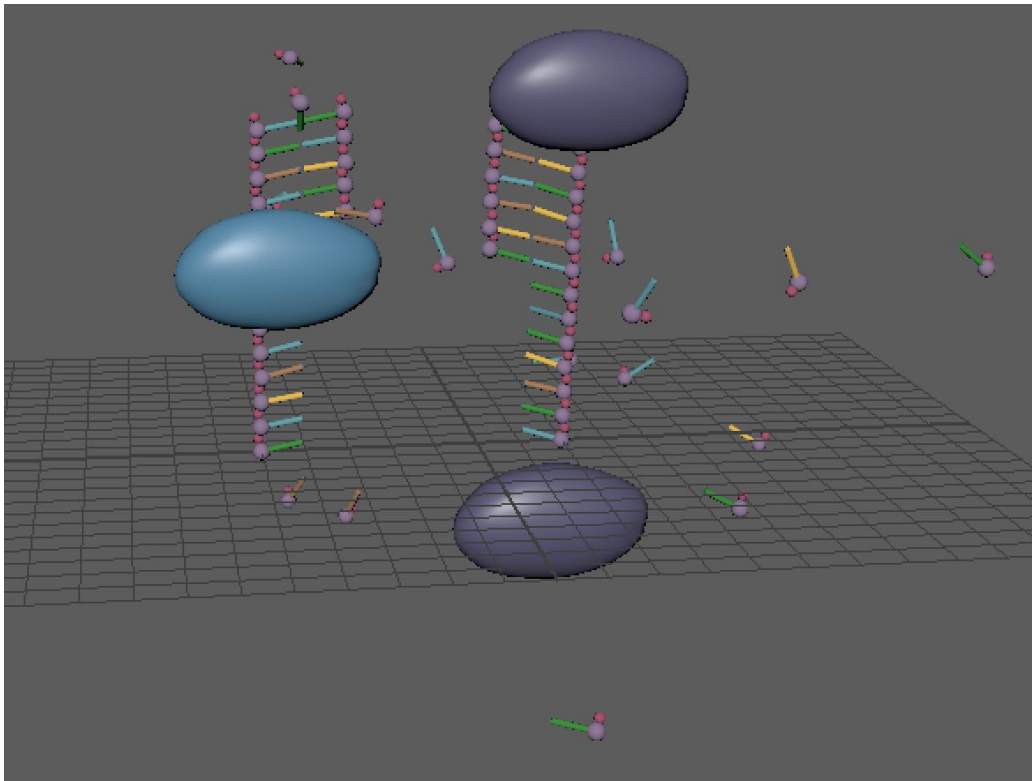


Figure 19: The DNA separation model during the animation process in which the two DNA strings are connected with new nucleotides with the enzyme DNA polymerase.

The general structure of the virtual reality lesson was made by composing several scripts in C# to regulate this structure. The virtual reality lesson was assembled using Unity3D and numerous scripts were created in Unity in order for the lesson to work. Specifically, a *PlayerEvents* script, to mainly check and update the status of the player and the controller. A *Pointer* script, to make and regulate the pointer that shows where the controller is pointed at. A *reticule* script to generate and regulate the end of the pointer and different sprites to show if the pointer was hitting an object. An *Animation* script to handle the animation and when it plays and stops. An *Interactable* script that regulates the newly appointed *interactable* layer for objects that can be interacted with in some way, which mainly included answers to questions and different parts of the 3D model that the user should see the name of when pointing and clicking on the part. A *StageHandler* script is included that handled the different stages of the lesson, which consisted of different questions, interactions, animation, and audio. These scripts are all shown in appendix 9 through 14.

The implementation of the files delivered by the teacher was the final step in making the lesson. The result included all the audio files that were recorded of the teacher according to the lesson plan. Text was introduced in addition to the audio files of the teacher asking

questions, this was a request from the teacher. The multiple-choice answers that were included in the lesson plan of the teacher are represented by text which is clickable by the student when participating in the lesson. Figure 20 shows one of these multiple-choice questions.

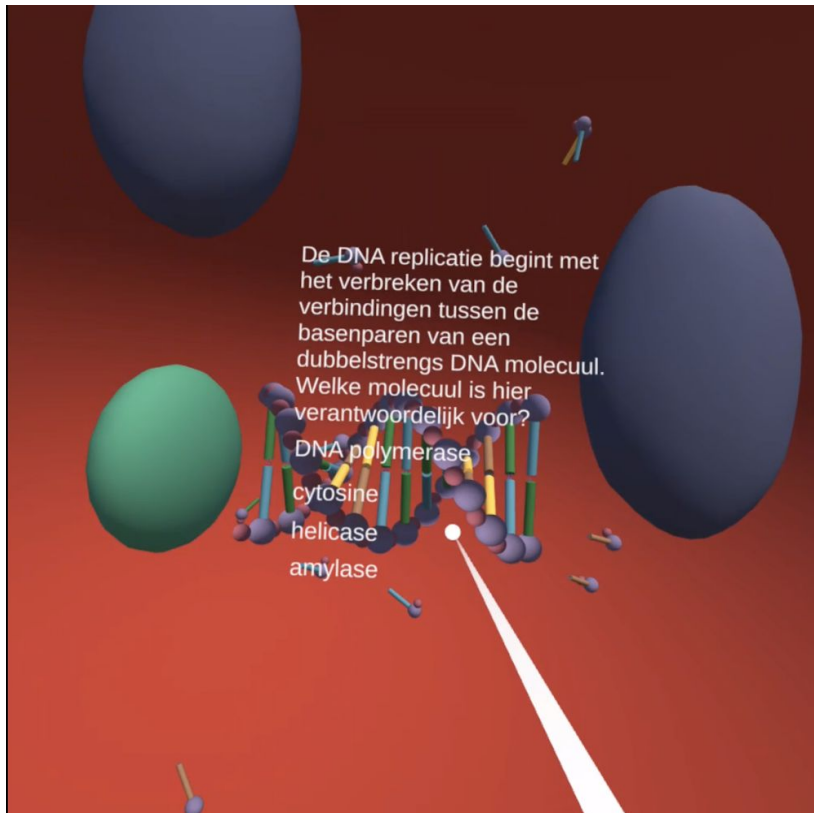


Figure 20: A screenshot of a screen recording of the VR lesson about DNA using the Oculus Go. The screenshot shows one of the multiple-choice questions with the four possible answers. (text is in dutch)

The form of interaction that was included consisted of the student being able to point to a part and see its name. This was implemented by using different tags for different objects and showing the tags to the user. An example of this can be seen in figure 21 and figure 22.

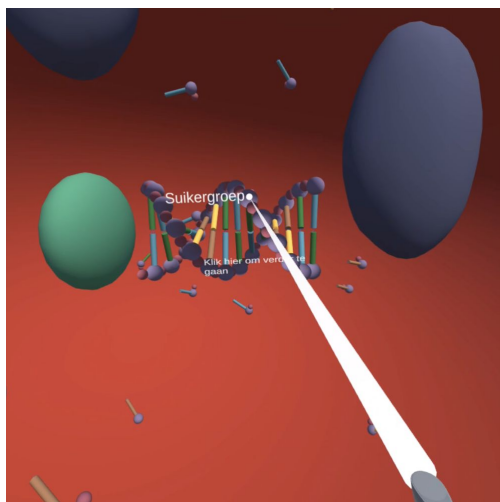


Figure 21: User pointing at deoxyribose in the VR lesson

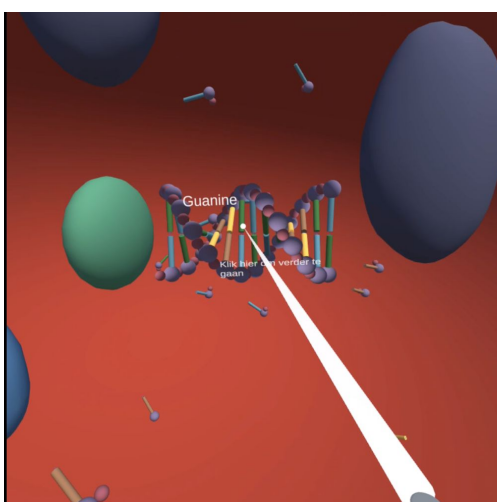


Figure 22: User pointing at guanine in the VR (sugar) lesson.

in

Chapter 6 - Evaluation

The most substantial prototype that has been made was a fully functional virtual reality lesson for DNA replication. Additional to this prototype, a clickable prototype of a teacher interface for a future VR based lesson development tool has been made. Both these prototypes need to be evaluated to process and analyze them correctly. The analysis will start with investigating the differences between the requirements and the actual prototype, this will include both prototypes. Then the feedback of the teacher on both prototypes were asked and analyzed. Additional to the teacher feedback, the student feedback on the virtual reality lesson will also be asked and analyzed.

6.1 Requirements vs implementation

The requirements list that was made in chapter three has been kept in mind during the design process with the goal of assuring all the requirements to be incorporated into the final design. However, not all the requirements have been implemented.

The implementation of the requirements that were introduced with the MoSCoW method and other requirements given in the requirements chapter were analyzed. The must-haves, questions for students, the ability for students to walk or look around and information, animations and visuals must be correct were all possible requirements. And have all been implemented. Two of the should-haves, interaction for the student with the environment and having a variety of text, sound and assignments with interaction were implemented as well, however, the other should-have, freedom for students to walk around, was not possible in a way that would not compromise the immersion of the student. This is the result of the students not having a specific area where they can really walk, as previously discussed in the practical requirements. By making the student virtually move around when the student is not actually walking around, the immersion level would go down due to having a noticeable feedback source, as discussed in chapter two. Both the could-haves, the ability for students to look around and think of what every part of the environment is and the ability for students to tinker with the environment were possible to be implemented. Regrettably, the tinkering with certain parts of the environment was not implemented. The reason for this was because the teacher did not see this as necessary since it was only a could-have, and implementing this would require more work and thus more time, which was not available. That is why it was decided to not implement the tinkering with the environment into the lesson for now.

The first could-have was implemented with the ability for students to click on certain parts of the DNA and see what the name of the part is. However, this feature, as described in the specifications, has not fully been implemented. The different parts that should have been clickable had to include the sugar, phosphate, adenine, guanine, thymine, cytosine and the freely floating nucleotide inside the cell nucleus, as described in the specification. In like manner, this has been the case for at least one of each of these parts. Unfortunately, not all of the parts were clickable. The reason for this was that there was simply not enough time to make all the different parts clickable since there were a lot of parts and this would have taken a lot of time. For that reason, only a few that were easily reachable for the students were clickable. Apart from the MoSCoW analysis, the teacher had another requirement, an animation should be available to show how the process of separation of two DNA strings is visualized. The animation was also implemented in the lesson. However, in the specification chapter, another 'animation' was mentioned, namely the animation of going from the skin to the cell nucleus. This was not achieved since there was limited time and implementing this feature would mean a 3D model of skin on a human would have had to be made, for which there was no time left.

In conclusion, it can be said that most of the requirements were implemented, the freedom for students to walk around, tinkering with certain parts of the environment and the animation of zooming into the skin until the cell nucleus was shown were all not implemented. However, all of the must-haves have been implemented and most of the other requirements and specifications as well.

6.2 Feedback from the teacher

Feedback on the lesson

The teacher got to see and experience the lesson when it was done, afterwards, the teacher got a video that was made with the VR gear during the VR lesson to watch the VR lesson again. The teacher was presented with nine questions to answer concerning this VR lesson. The questions, including the answers, can be seen below:

1. *To which extent does the VR lesson, as you have designed it, correspond to the virtual lesson that was made?*

This is a tough question since I did not yet have a concrete image of the possibilities of VR. However, all the components that were discussed were incorporated into the virtual reality lesson.

2. *What do you believe is going right in the VR lesson, and why?*

I think it is not yet a fully self-contained lesson, but that you should speak of a lesson element or lesson activity. What I like about the VR experience is that the students can actually see the process happening. The added value of this is that the students can see that the nitrogen bases are 'floating' around in the cell nucleus.

3. *What do you believe is going wrong in the VR lesson, and why?*

Nothing was going wrong.

4. *What would you want to add / what do you think is missing?*

A lesson or lesson plan in which this activity has been integrated.

5. *What would you want to remove/change?*

I would not want to remove anything. However, I would want to change a number of things. For example, during the voice-overs I am reading through the text very fast, this could be done a lot slower. The difference between nitrogen bases and nucleotides is not clarified in the lesson, that can be improved. It also seems like the part where students can look around does not go smoothly yet. Helicase separates the whole DNA-molecule in the animation, in reality, this does not happen. It would have been nice if the DNA-molecule that is seen in the animation would have been longer, and that DNA-helicase separates the DNA-strings while DNA-polymerase is doing its job. This is not the case right now. For this reason, you do not see why the Okazaki-fragments are being formed, while this is an important part of DNA replication for vwo classes. So, for now, this would be usable for HAVO 4 and HAVO 5 but not for vwo.

6. *Are there options or features that you would want to implement? (other than asking questions, adding text, and adding voice-overs)*

None that I can think of.

7. *Do you feel like students could benefit from experiencing this lesson, and why?*

Yes, this experience will give the students another way of experiencing the process

8. *Do you think the aspects that you incorporated in your MoSCoW analysis are incorporated in this lesson correctly/incorrectly? Which ones do you feel were incorporated incorrectly/correctly and why?*

Predominantly I think the aspects were incorporated correctly, however, only one path can be followed. It would be nice if there were some embranchements, so you can differentiate between students. Suppose a student would get the wrong answer to a question, you could then give that student some additional explanation or let them see an animation first. However, due to time limits, this was not feasible.

9. *Do you have any additional comments on the VR lesson?*

I got a nice first impression on the use of VR. I think it is important to start with a concrete question or problem. When designing this lesson we decided in half an hour what we wanted to do, yet, I actually would have needed more time to excogitate this clearly. I think this is something the teacher should do before the designer can start on making the lesson.

Concludingly, it can be stated that the VR lesson can be optimized more in the teacher's opinion. Concretely, incorporating branches to the path could help distinguish between the needs of students and some changes to the 3D model and to the animation can help to bring the virtual reality lesson to a new level. Additionally, the comment the teacher made on this not being a self-contained lesson is something that should be recognized. Especially considering the overall result of the VR 'lesson' has a duration of fewer than 10 minutes on average.

Feedback on the interface

The teacher was able to try out this prototype and give some additional feedback on it. This was done in a structured interview. The questions that were asked, including the answers, were:

1. *What goes wrong or could be done better?*

Nothing really went wrong

2. *What goes well?*

The interface was very clear. I also really like that you can add 3D models to a scene.

3. *What is missing?*

A platform to see the answers to the questions is missing. Furthermore, everything should be clickable and interactive instead of only a few options. I also missed the movement within a frame. Something I would want to add would also be adding a question after a certain amount of time, so the students could look around for a minute before a question appearing.

4. *What should be removed?*

Nothing that I can think of.

5. *Does this appear intuitive and easy to use?*

Yes, it is all very logical.

The conclusion that could be drawn from this is that overall the interface as it is designed is perceived as logical and intuitive and meets most of the requirements of the teacher.

However, further improvements can be made by adding some environment for the teacher to view the answers of the students in the virtual reality lesson after such a lesson has taken

place. Additionally, movement within the 3D environment for the teacher when making the lesson should be added in a way that the teacher can move through the 3D models. Another additional feature can be to add a timer between questions, assignments, and interactions, that the teacher can use to let the students look around for a certain amount of time.

6.3 Feedback from the students

Ten students of a 5 HAVO biology class were asked to view the VR lesson and participate in a small survey. The first part of the survey consisted of the System Usability Scale (SUS). The second part consisted of additional questions using a 5 point Likert-scale.

Method

During their biology lesson, students were asked if they wanted to participate in a study regarding the use of virtual reality in the classroom. Ten students that were willing to participate were chosen randomly from the group. Before the students participated in the VR lesson and survey that their teacher asked them to read the contents of their biology book that explained DNA replication. After reading the book, the students were directed to the inside of a classroom one at a time. There it got explained to them that research was being done regarding the use of virtual reality in the classroom and that a biology lesson had been made that they would get to experience. The students got a small explanation regarding the virtual reality gear and how to handle the controller. They were told that they had all the time they needed for the lesson, and they could ask questions or stop the lesson at any point. After the students experienced the lesson, they were asked to fill in a survey. No time limit was put upon taking the survey.

The SUS and its score

The System Usability Scale, created by John Brooke in 1986, has become an industry standard to evaluate the usability of systems (Sauro, 2011). This usability scale has been chosen due to its reliable results in small sample sizes and the simplicity of the questionnaire ("System Usability Scale," 2013). Additionally, since it is a well-known method, the results will be easy to interpret and the results will bear more meaning than the results of a lesser-known test. The SUS consists of ten questions that can be answered with 5 response options that range from strongly disagree to strongly agree:

1. I think that I would like to use this system frequently.
2. I found the system unnecessarily complex.
3. I thought the system was easy to use.

4. I think that I would need the support of a technical person to be able to use this system.
5. I found the various functions in this system were well integrated.
6. I thought there was too much inconsistency in this system.
7. I would imagine that most people would learn to use this system very quickly.
8. I found the system very cumbersome to use.
9. I felt very confident using the system.
10. I needed to learn a lot of things before I could get going with this system.

The SUS-test score can be calculated by using a formula in which each answer has a specific number of points. Where strongly agree is five points and strongly disagree is one point, as figure 23 illustrates. The formula is for each even question $5 - X$, and for odd-numbered questions $X - 1$, where X is the number of points of the question. All these points need to be added and the final number needs to be multiplied by 2,5. The highest possible score is 100 and the lowest is 0. The ten SUS scores that resulted out of the ten questionnaires that have been made by students have been added and divided by 10 to get the average score of this system. The average score is 74. A SUS score of 74 converts to the 70% percentile rank. This means that the usability of this product has the perceived usability of above 70% of all products tested and can be interpreted as a grade of a B- (Sauro, 2011).

Strongly Disagree 1	2	3	4	Strongly Agree 5
<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>	<input type="radio"/>

Figure 23: The SUS points per answer.

The questionnaire

Additional to the SUS, a questionnaire was constructed for the students to give their opinion on the virtual reality lesson. The questionnaire consisted of eight questions where answers could be given according to the Likert-scale.

The questions that were constructed were designed to get a better understanding of the benefit of the VR lesson regarding the students' knowledge and understanding of DNA replication, question 1 and 2 were designed regarding this topic, of the students' attitude towards the use of virtual reality in the classroom, question 3, 4 and 5 were designed to

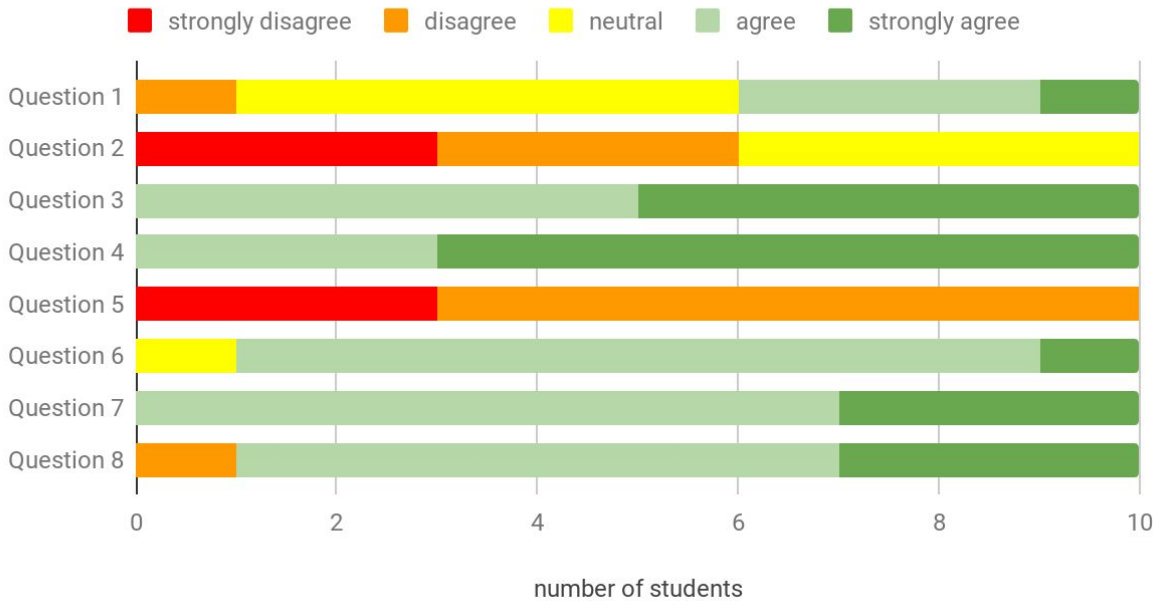
address this, and to check if the VR lesson was understandable by the students, this concerns question 6, 7 and 8.

The questionnaire can be seen in table 3. The answers to the questions have been put in a diagram which can be seen in figure 24.

	Strongly agree	agree	neutral	disagree	strongly disagree
Question 1: I thought the explanation of DNA replication that was seen in this lesson was clearer than the explanation of DNA replication in the book					
Question 2: I thought this VR lesson added <u>nothing</u> to my knowledge or understanding of DNA replication					
Question 3: I would like to use virtual reality more often in the classroom					
Question 4: I thought this VR lesson was nice to experience					
Question 5: I found it difficult to concentrate within the virtual environment					
Question 6: The structure of the DNA was clear in the VR lesson					
Question 7: The separation of the two DNA strings was clearly represented					
Question 8: I understand what the animation was trying to illustrate					

Table 3: The student survey that was given to students after participating in the VR lesson.

Answers to student questionnaire



Question 1: I thought the explanation of DNA replication that was seen in this lesson was clearer than the explanation of DNA replication in the book

Question 2: I thought this VR lesson added nothing to my knowledge or understanding of DNA replication

Question 3: I would like to use virtual reality more often in the classroom

Question 4: I thought this VR lesson was nice to experience

Question 5: I found it difficult to concentrate within the virtual environment

Question 6: The structure of the DNA was clear in the VR lesson

Question 7: The separation of the two DNA strings was clearly represented

Question 8: I understand what the animation was trying to illustrate

Figure 24: Diagram of the answers of students to the student questionnaire.

The answers to the questionnaire can be analyzed by looking at the wished result compared to the actual result. The first question, **I thought the explanation of DNA replication that was seen in this lesson was clearer than the explanation of DNA replication in the book**, is one that if answered in an agreeing manner reflects positively on the virtual reality lesson. 40% of the students answered agreeably, whereas only 10% answered in a disagreeing manner. the other 50% answered neutral. A conclusion that can be drawn from this is that more students found the lesson better than in the book than students who did not found it better, however half of the students answered neutral. This question directly connects to the benefit of using

this lesson to explain DNA replication, since a better explanation could mean a better understanding by students.

Conjointly to the first question, the second question also looked into the benefit of using this VR lesson in the student's understanding. The second question, **I thought this VR lesson added nothing to my knowledge or understanding of DNA replication**, should inspire a negative answer to ensure a positive correlation between this lesson and the student's understanding or knowledge on the subject. 60% either disagrees or strongly disagrees, which is a desirable result. The other 40% was neutral on this question, which means 0% agreed. A conclusion that can be drawn from this is that most students found that this virtual reality lesson on DNA replication helped them in their knowledge or understanding of the subject.

The third question, **I would like to use virtual reality more often in the classroom**, addresses the willingness of students to use VR in the classroom, which is preferred if not necessary for teachers if they want to use virtual reality to teach their students. All the students agreed or strongly agreed with this statement, this means that every student would like to use VR more often in the classroom.

The fourth question also ascribes to the willingness of students to use virtual reality. Additionally, it also looks at the experience of this virtual reality lesson. The statement, **I thought this VR lesson was nice to experience**, was either agreed or strongly agreed with by all the students. That is a positive answer, which means that this virtual reality lesson on DNA was experienced positively by all students.

I found it difficult to concentrate within the virtual environment, which was the fifth question that the students were asked. A positive result here would be for the students to disagree since it is not wanted for the students to not be able to concentrate within this VR lesson. Fortunately, all answers were answered with a disagree or strongly disagree.

The sixth question, **The structure of the DNA was clear in the VR lesson**, looks at the actual content of the lesson. 10% of the students did not agree but was neutral to this statement. The other 90% did agree with this statement, which means that most of the students thought the structure of DNA was clear. The importance of this question is to see if the other questions regarding this lesson's influence on student knowledge or understanding were not compromised by the quality of the 3D DNA model. As a conclusion, it can be said that since none of the students disagreed that the structure of the 3D model was clear, the quality of the 3D model regarding the structure did not compromise any results in a negative manner.

The seventh question also calls on the 3D model and with that the animation. The statement, **The separation of the two DNA strings was clearly represented**, was agreed with by all students. These answers are positive since this means all the students clearly saw the separation of the two DNA strings. This, similar to the previous question, also inspects the influence of the quality of the 3D model and its animation on any of the questions. This question, in conjunction with the previously analyzed question, confirms that the questions were not affected by the possible bad quality of the 3D model and animation.

The last question is also trying to ensure that the quality of the animation did not influence the answers of this questionnaire in a negative way. This last question, **I understand what the animation was trying to illustrate**, is also to check if the student has paid attention to the audio in the lesson since the audio narrated the animation. Therefore agreeing answers from the students would be wanted and expected. However, 1 student, 10%, did not agree with this statement. The other 90% did agree. The conclusion that can be drawn from this is that most of the students understood the animation and listened to the audio, while one student did not understand. Consequently, this means that the answers of one student to the questions regarding the understanding of the topic due to the VR lesson may be negatively influenced by not understanding the animation.

Chapter 7 - Conclusion

The main objective of this research was to discover what aspects and features are needed and wanted in a virtual reality tool for teachers where a teacher can make guided lessons with the use of premade 3D models from third parties. This main objective was achieved by making a prototype of a lesson that should be able to be made with this tool with the help of co-creation. In order to achieve this goal, a number of sub-questions had to be asked first.

The first sub-question was: *How can teachers implement virtual reality in a way that it can help students to get a better understanding of certain subjects?* This question has been answered in the state-of-the-art research and led to the conclusion that keeping the immersion and motivation levels high would help students get a better understanding of the subject. Furthermore, the conclusion that the method to keep the immersion high would be to use motion-tracked controllers, make an environment where the students are in control of their own navigation, making an environment where there is guidance by teachers inside the environment and make sure that an orientation process is integrated into the learning path for the student. All these aspects were important and therefore they were tried to implement into the final prototype. The guidance of teachers inside the environment was incorporated in the virtual reality lesson by letting the teacher add voice-overs in which the teacher was guiding the students. Additionally, the orientation process has been implemented by letting the students know their whereabouts in a voice-over at the beginning of the lesson. Furthermore, navigational control was incorporated in the movement of the head.

Along with a lot of other requirements, both the motion-tracked controllers and navigational control were taken into account with the next sub-question: *which type of virtual reality tools should be used?* The concluding virtual reality tool that was best for this project was a standalone VR device. One of those standalone VR devices, the Oculus Go, was used to show the lesson to the students.

The third sub-question read: *What is the available 3D content that can be useful in VR on the topic of biology, which can be used for educational purposes?* And could be answered after some research into the topic, the needs, and the available 3D models. In conclusion, the topic that was chosen was DNA, more specific DNA replication.

The fourth sub-question was possibly the biggest question: *What is needed to make a guided virtual reality lesson with voice recordings where teachers are satisfied with the interaction?* This question was answered by making such a guided lesson by using co-creation with a teacher. The final lesson that was designed was the answer to this

question. The important lessons that could be concluded from this design were that animations can be an important aspect of a lesson in VR. Additionally, there must be a source of information in the lessons, this can be in the form of voice-overs. Furthermore, questions, assignments, and interaction are important aspects when designing a lesson. Therefore, a feedback source is needed for the teachers to be able to see the answers to the questions.

Additionally, to the previous question, the fifth question also looks at the teacher satisfaction: *What is the reaction of the teacher to the created virtual reality lesson?* This question looks mainly at the difference between the design and the result of the lesson. The teacher was asked to give feedback on the VR lesson and the feedback gave some possible options to further develop the lesson to make it better. Overall, the teacher was satisfied with the result.

Furthermore, the last question also looks at the reaction, only of the students instead of the teacher: *What is the reaction to the student interaction with the virtual reality lesson?* The conclusion that was drawn for this question was that the lesson was positively received by the students. This conclusion is important to check if students are open to virtual reality lessons made by a teacher and is an important aspect to consider before making a virtual reality tool.

The virtual reality lesson that has been created was positively received by students and the biology teacher. Additional changes that could improve the lesson include, incorporating branches to help distinguish between the needs of different students and make some changes to the 3D model and to the animation.

Additional to the improvements of the VR lesson, the virtual reality lesson also helped identify important aspects for the development of a virtual reality tool for teachers. The main aspects that are needed in such a tool are the possibility to add animations, the ability to add text, questions and voice-overs, and the option to have different stages and let the teachers decide when the student goes to another stage are important. Additionally, there needs to be some sort of library where teachers can find 3D models, animations and environments because the teachers should only have to deliver the lesson plan and not any 3D content in the virtual reality environment. Moreover, an environment for the teacher to see the results of the questions that the students answered in the VR lesson is desired.

Chapter 8 – Future Work

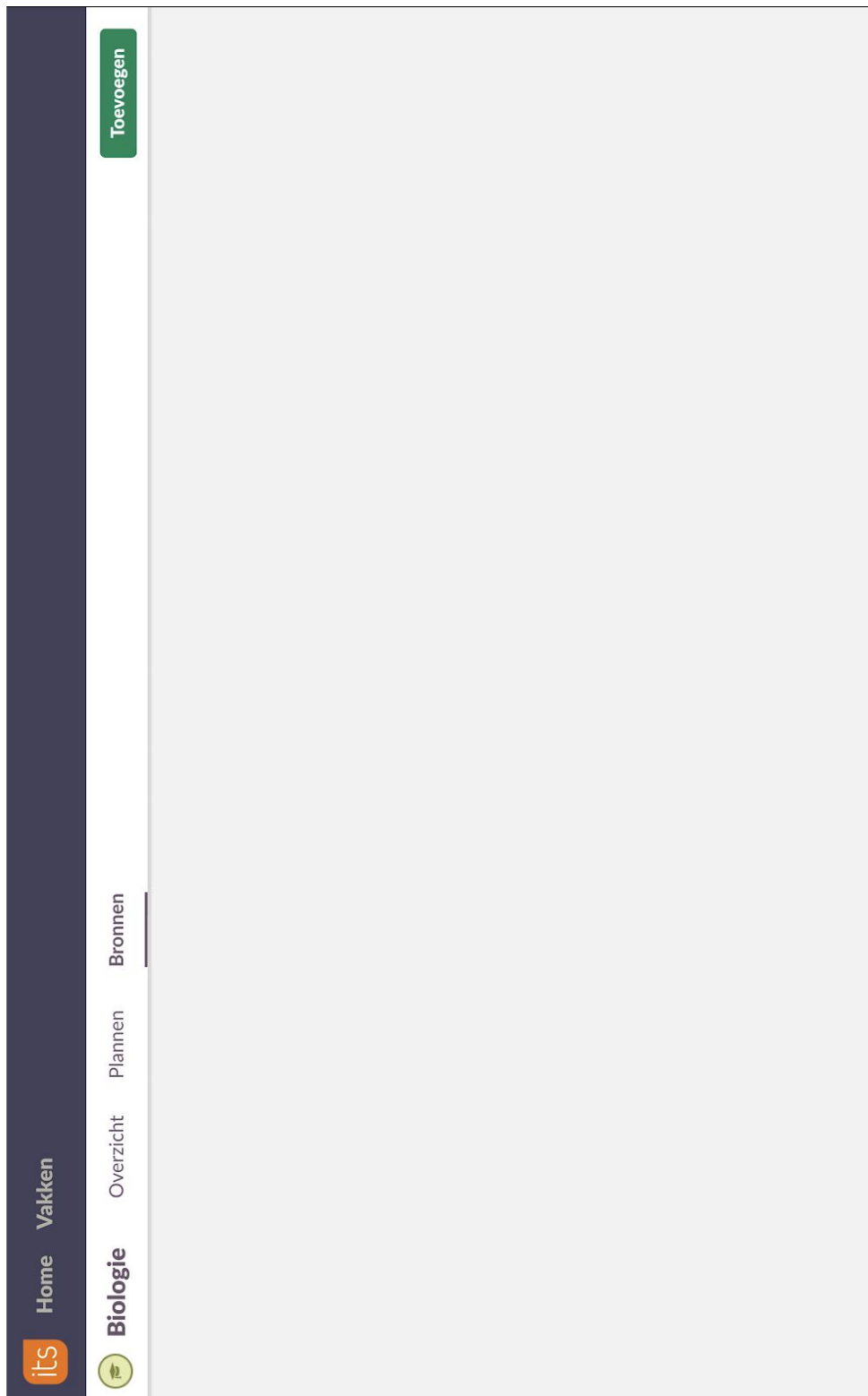
Working on a virtual reality tool has identified some gaps in the current knowledge that could be remedied by additional research.

One of these gaps includes the research that has been done regarding if teachers are qualified to make virtual reality lessons. Research on this topic is minimal, nonetheless, this research could be important to address the competencies of a teacher regarding making lessons with the use of virtual reality. Additionally, research can be done concerning the best way to make a virtual reality lesson in order to reach the full educational potential regarding the use of virtual reality in the classroom.

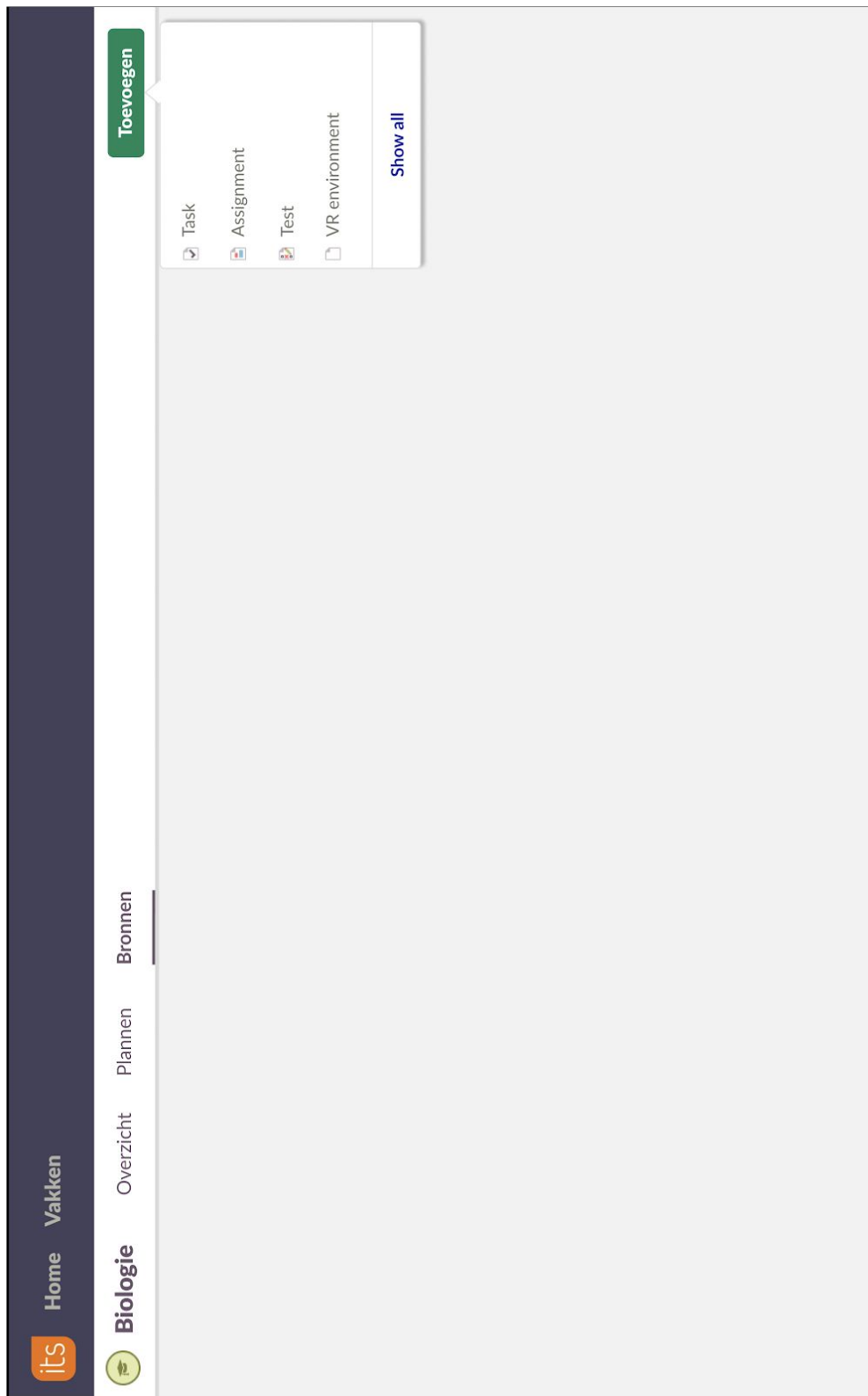
Furthermore, research on the benefit of a tool where the teacher can make a virtual reality lesson needs to be done. This could include possible time benefits for teachers and possible learning benefits for students.

Since only one teacher was consulted, it is advised to repeat this research with multiple different teachers to check for different results. Additionally, this research could be repeated with school subjects other than biology. Moreover, different teachers should be asked their opinion on the functionalities of the virtual reality tool as they are defined in this research project. Additionally, the lesson that was made could be investigated and developed further. Finally, a virtual reality tool for teachers still needs to be made, researched and analyzed. This would include more research regarding the usability of such a tool, and research into making the tool teacher-friendly.

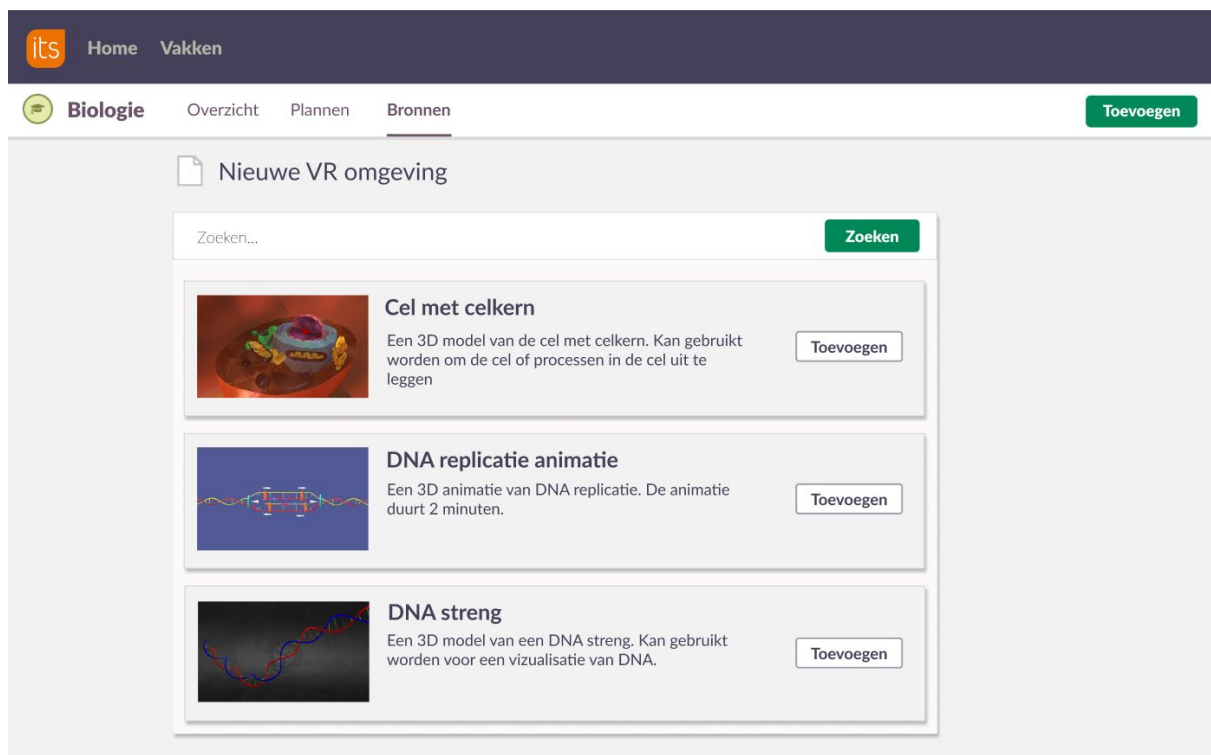
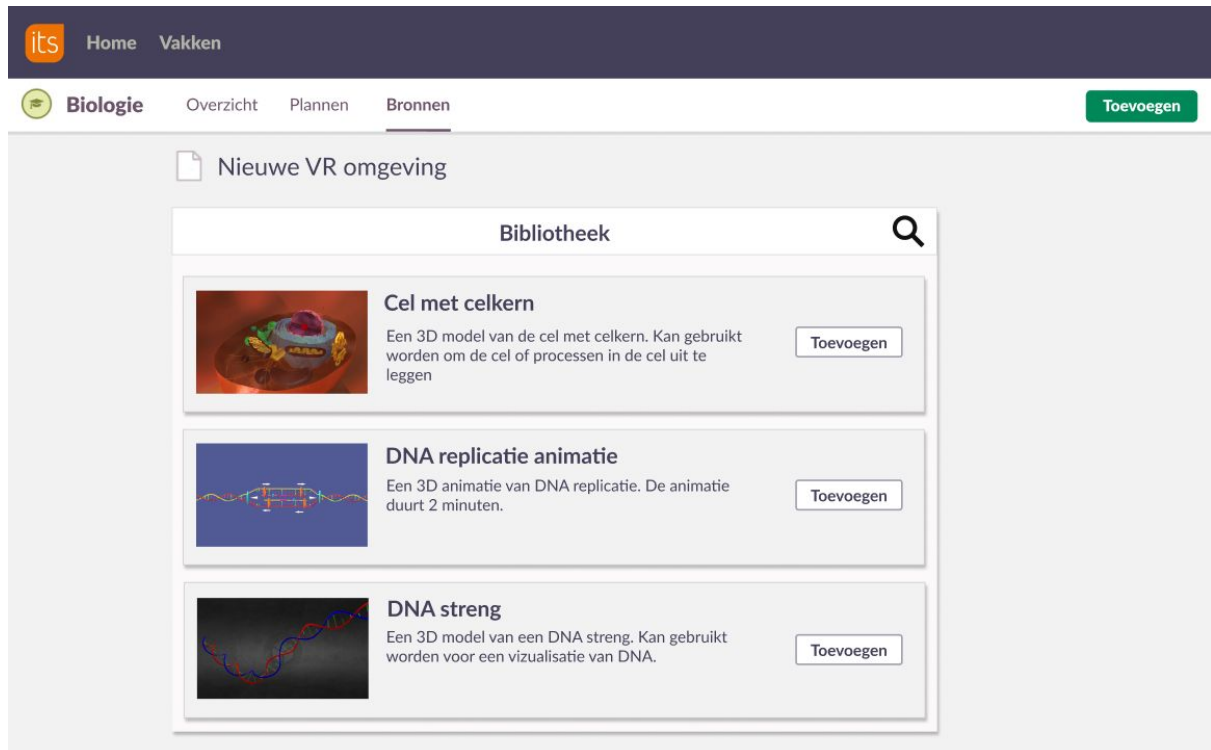
Appendix 1: start screen of the interface prototype



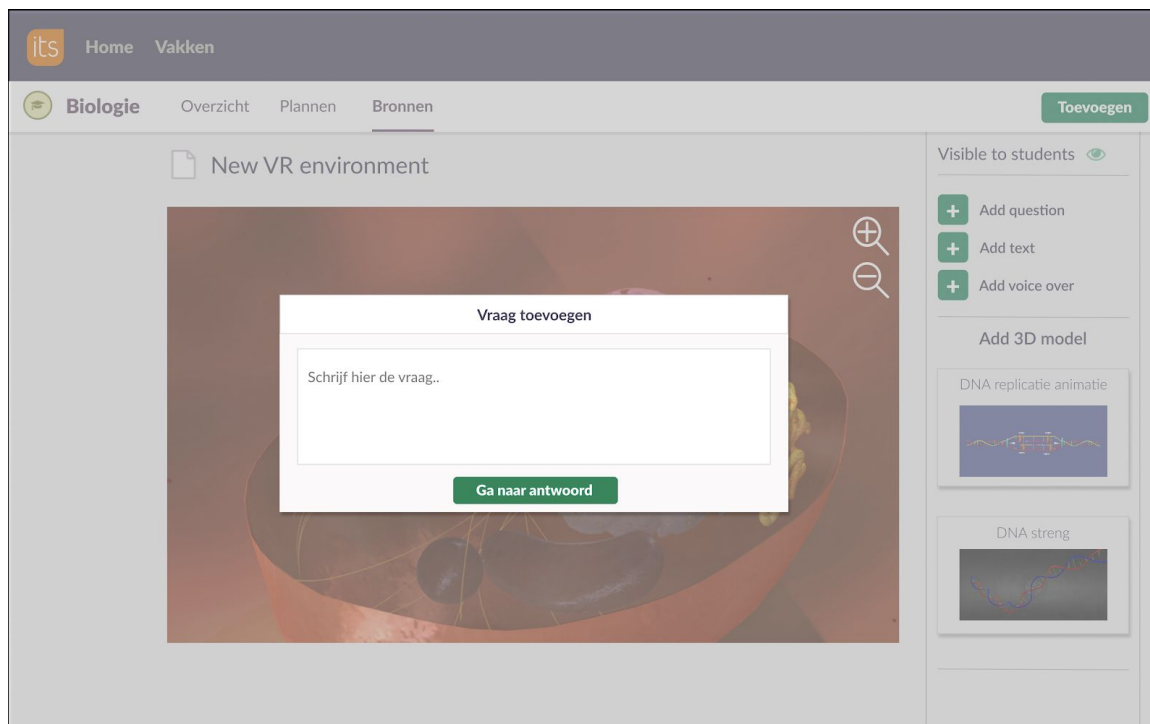
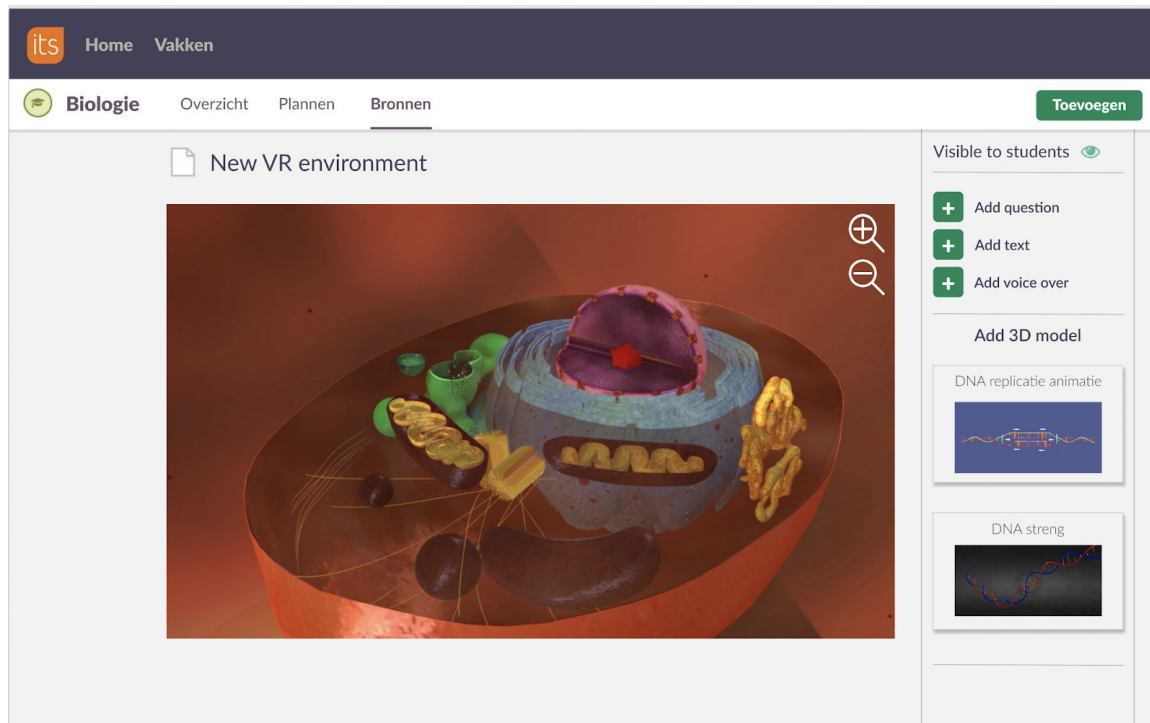
Appendix 2: screen 1 of the interface prototype



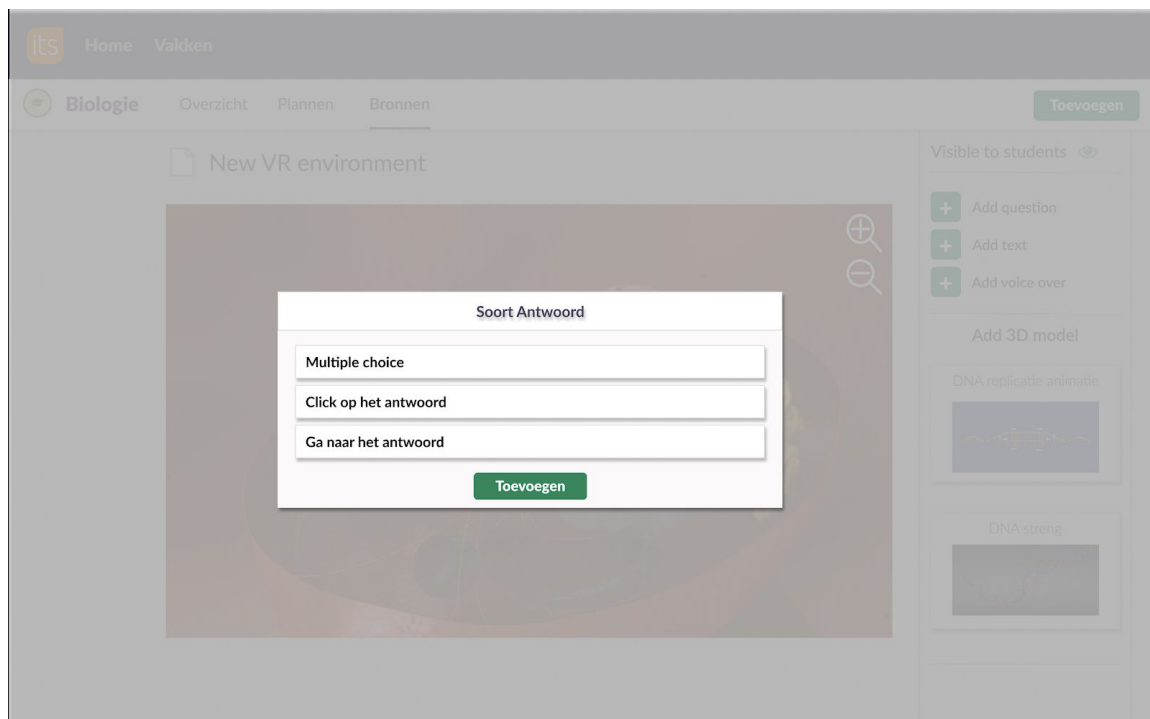
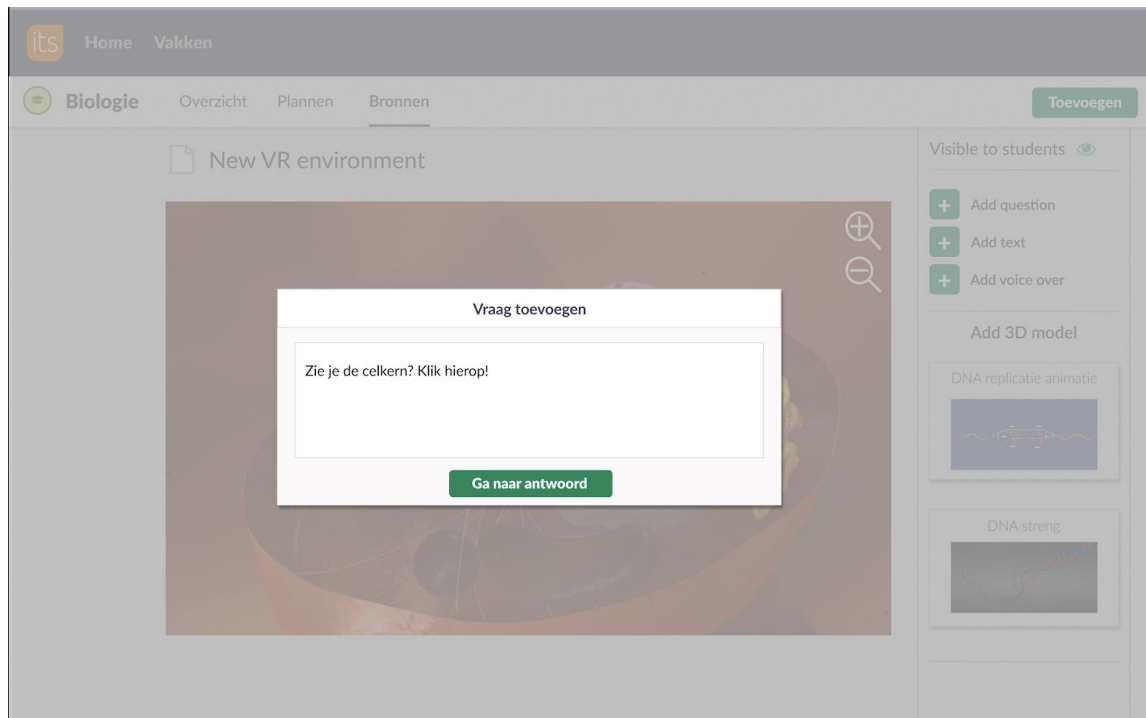
Appendix 3: screen 2 and 2b of the interface prototype



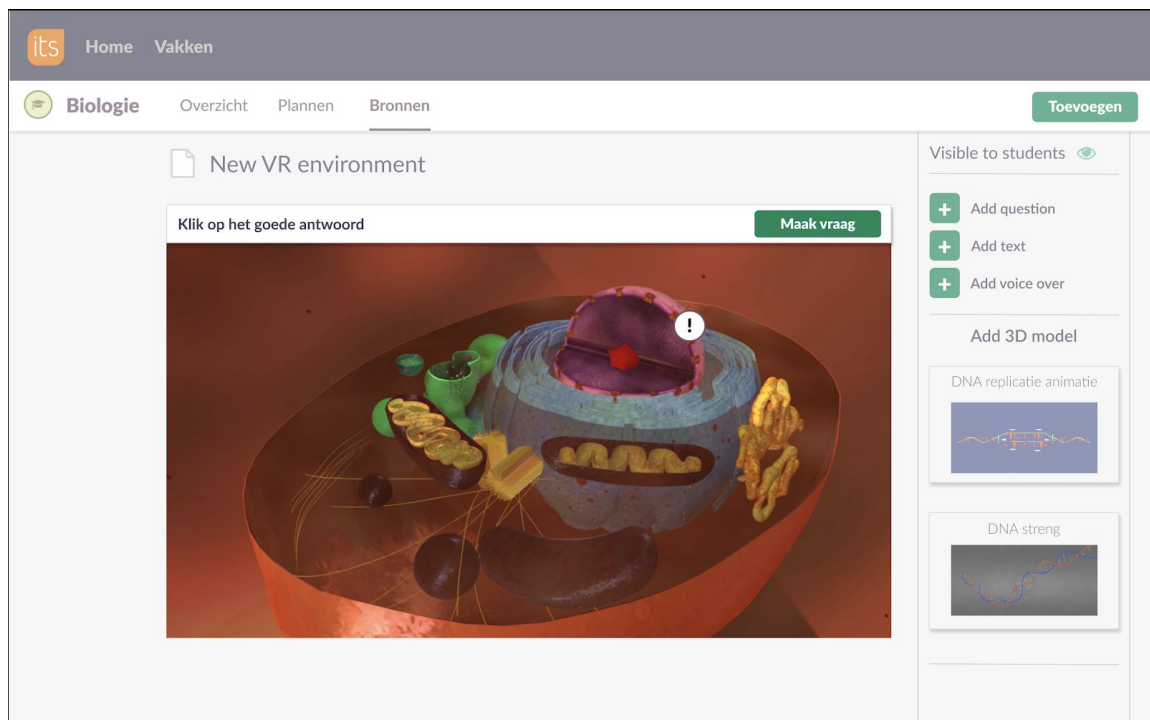
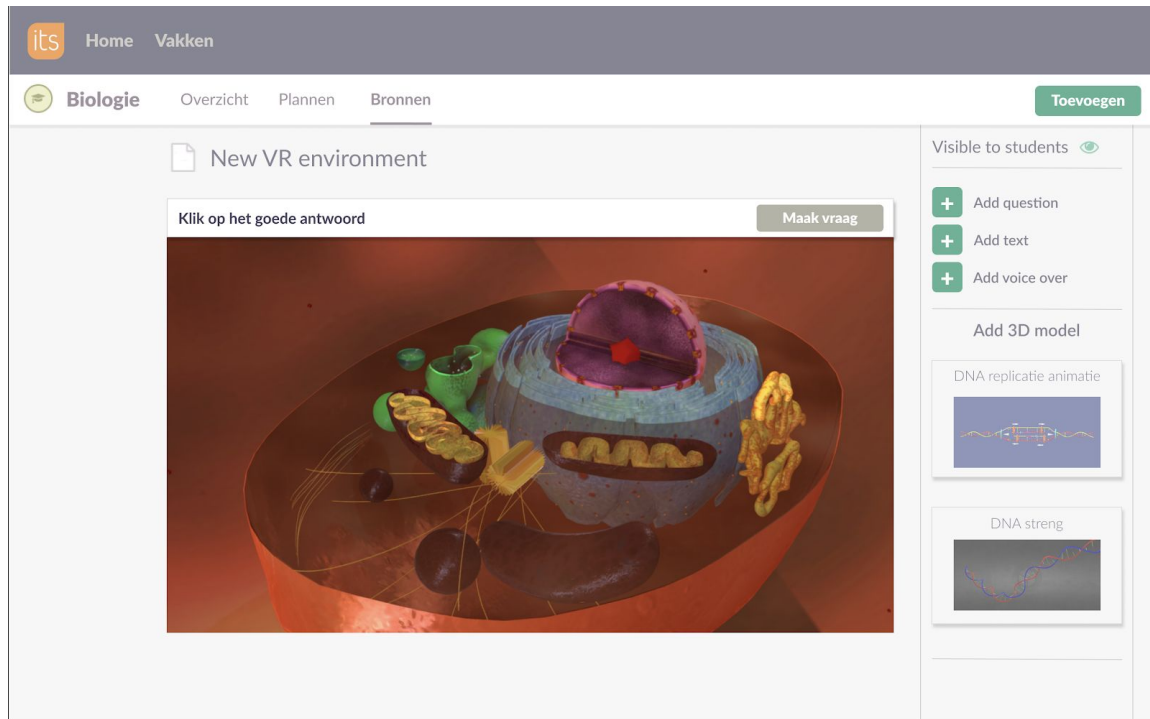
Appendix 4: screen 3 and 4 of the interface prototype



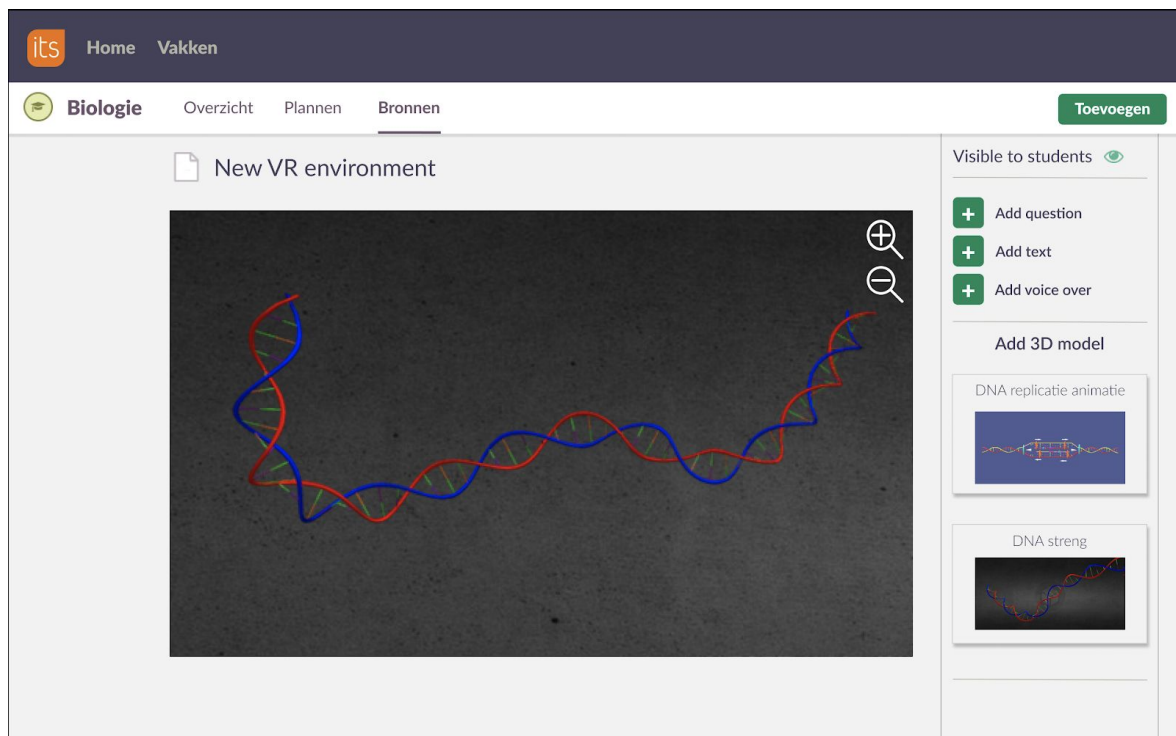
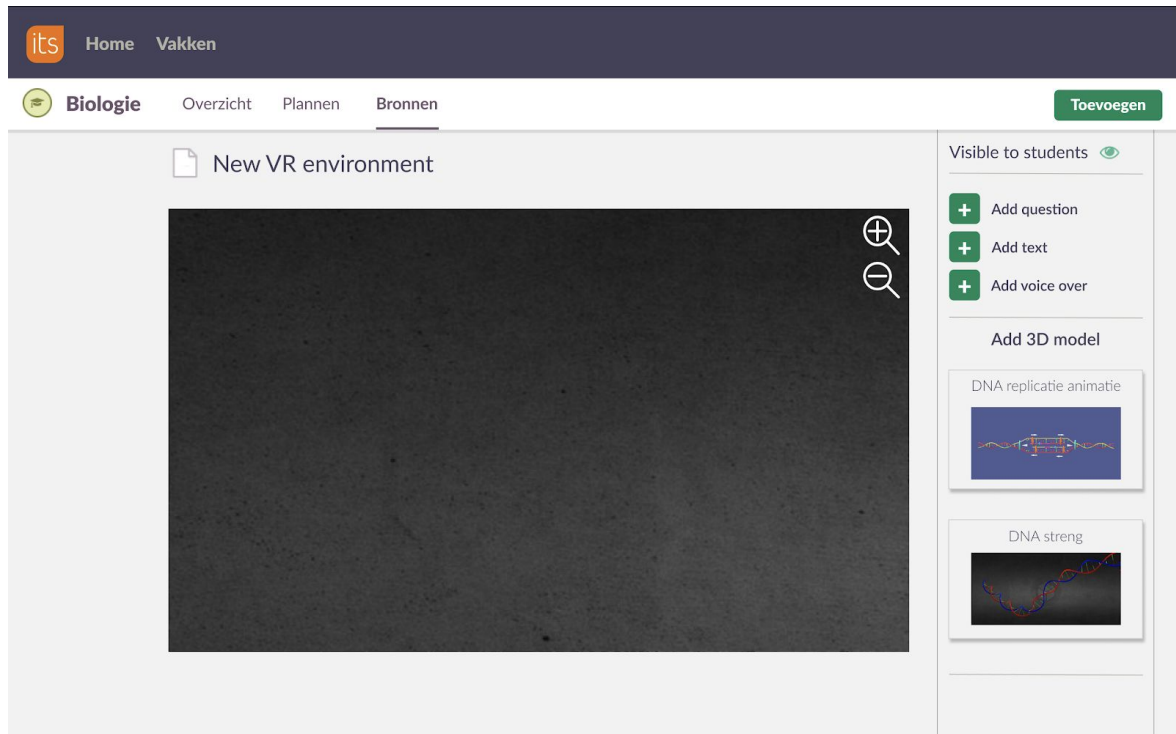
Appendix 5: screen 5 and 6 of the interface prototype



Appendix 6: screen 7 and 8 of the interface prototype



Appendix 7: screen 11 and 12 of the interface prototype



Appendix 9: StageHandler.cs

```
using UnityEngine;
using TMPro;

public class StageHandler : MonoBehaviour
{
    #region sound
    public AudioClip introductionSound;
    public AudioClip firstQuestionSound;
    public AudioClip lookAroundYouSound;
    public AudioClip secondQuestionSound;
    public AudioClip afterAnimationSound;
    public AudioClip afsluiting;
    public AudioSource source;
    #endregion

    #region text
    public GameObject textCanvas;
    private TextMeshPro m_Text;
    public GameObject ansA;
    private TextMeshPro m_TextAnsA;
    public GameObject ansB;
    private TextMeshPro m_TextAnsB;
    public GameObject ansC;
    private TextMeshPro m_TextAnsC;
    public GameObject ansD;
    private TextMeshPro m_TextAnsD;
    public GameObject nextText;
    private TextMeshPro m_GoNextText;

    private int m_questionNumber;
    #endregion

    public GameObject DNA;
    private AnimationScript m_animation;
    private int stage = 1;

    private bool hasPlayed = false;

    private void Awake()
    {
        source = GetComponent();
    }
}
```

```

    m_Text = textCanvas.GetComponent<TextMeshPro>();
    m_TextAnsA = ansA.GetComponent<TextMeshPro>();
    m_TextAnsB = ansB.GetComponent<TextMeshPro>();
    m_TextAnsC = ansC.GetComponent<TextMeshPro>();
    m_TextAnsD = ansD.GetComponent<TextMeshPro>();
    m_GoNextText = nextText.GetComponent<TextMeshPro>();
    m_animation = DNA.GetComponent<AnimationScript>();
}

// Update is called once per frame
private void Update()
{
    // Check for sound
    SoundControl();
}

private void SoundControl()
{
    if (stage == 1)
    {
        source.PlayOneShot(introductionSound, 1F);
        stage++;
    }
    if (stage == 2 && !source.isPlaying && !hasPlayed)
    {
        source.PlayOneShot(firstQuestionSound, 1F);
        hasPlayed = true;
        AskQuestion(1);
    }
    if (stage == 3 && !source.isPlaying && !hasPlayed)
    {
        source.PlayOneShot(lookAroundYouSound, 1F);
        hasPlayed = true;
        AskQuestion(2);
    }
    if (stage == 4 && !source.isPlaying && !hasPlayed)
    {
        source.PlayOneShot(secondQuestionSound, 1F);
        hasPlayed = true;
        AskQuestion(3);
    }
    if (stage == 5 && !source.isPlaying && !hasPlayed)
    {
        AskQuestion(0);
        m_animation.StartAnimation();
    }
}

```

```

        hasPlayed = true;
        Invoke("SetStage", 16);
    }
    if (stage == 6 && !source.isPlaying && !hasPlayed)
    {
        source.PlayOneShot(afterAnimationSound, 1F);
        m_animation.SetAnimation(false);
        hasPlayed = true;
        SetStage();

    }
    if (stage == 7 && !source.isPlaying && !hasPlayed)
    {
        source.PlayOneShot(afsluiting, 1F);
        hasPlayed = true;
        SetStage();

    } if (stage == 8 && !source.isPlaying)
    {
        m_animation.SetAnimation(true);
    }
}

private void AskQuestion(int questionNr)
{
    ansA.GetComponent<BoxCollider>().enabled = true;
    ansB.GetComponent<BoxCollider>().enabled = true;
    ansC.GetComponent<BoxCollider>().enabled = true;
    ansD.GetComponent<BoxCollider>().enabled = true;

    m_questionNumber = questionNr;
    string question;
    string a;
    string b;
    string c;
    string d;
    switch (questionNr)
    {
        case 1:
            question = "In welke fase van de celcyclus vindt DNA
replicatie plaats?";
            a = "G1-fase";
            b = "S-fase";
            c = "G2-fase";
            d = "M-fase";

```

```

        break;
    case 2:
        question = "";
        a = "";
        b = "";
        c = "";
        d = "";
        ansA.GetComponent<BoxCollider>().enabled = false;
        ansB.GetComponent<BoxCollider>().enabled = false;
        ansC.GetComponent<BoxCollider>().enabled = false;
        ansD.GetComponent<BoxCollider>().enabled = false;
        nextText.GetComponent<BoxCollider>().enabled = true;
        m_GoNextText.SetText("Klik hier om verder te gaan");
        break;
    case 3:
        question = "De DNA replicatie begint met het verbreken
van de verbindingen " +
            "tussen de basenparen van een dubbelstrengs DNA
molecuul. " +
            "Welke molecuul is hier verantwoordelijk voor?";
        a = "DNA polymerase";
        b = "cytosine";
        c = "helicase";
        d = "amylase ";
        break;
    default:
        question = "";
        a = "";
        b = "";
        c = "";
        d = "";
        ansA.GetComponent<BoxCollider>().enabled = false;
        ansB.GetComponent<BoxCollider>().enabled = false;
        ansC.GetComponent<BoxCollider>().enabled = false;
        ansD.GetComponent<BoxCollider>().enabled = false;
        break;
}

m_Text.SetText(question);
m_TextAnsA.SetText(a);
m_TextAnsB.SetText(b);
m_TextAnsC.SetText(c);
m_TextAnsD.SetText(d);
}

```

```
public int GetGoodAnswer()  
{  
    switch (m_questionNumber)  
    {  
        case 1: return 2;  
        case 2: return 0;  
        case 3: return 3;  
        default: return 0;  
    }  
}  
  
public int GetStage()  
{  
    return stage;  
}  
  
public void SetStage()  
{  
    stage++;  
    hasPlayed = false;  
}  
}
```

Appendix 10: Interactable.cs

```
using System.Collections;
using System.Collections.Generic;
using UnityEngine;
using TMPro;

public class Interactable : MonoBehaviour
{
    public GameObject textCanvas;
    public GameObject ansA;
    public GameObject ansB;
    public GameObject ansC;
    public GameObject ansD;
    public GameObject next;
    public GameObject stageHandlerObject;

    private StageHandler stageHandler;
    private int stage;

    public void Pressed()
    {
        stageHandler = stageHandlerObject.GetComponent<StageHandler>();
        stage = stageHandler.GetStage();
        int q = stageHandler.GetGoodAnswer();

        if (q != 0 && (stage == 2 || stage == 4 ))
        {
            HandlePressedQuestion(q);
        }
        else if (stage == 3)
        {
            StageThree();
        }
        else
        {
            textCanvas.GetComponent<TextMeshPro>().SetText(" ");
        }
    }
}
```

```

private void HandlePressedQuestion(int answer)
{
    ansA.GetComponent<BoxCollider>().enabled = true;
    ansB.GetComponent<BoxCollider>().enabled = true;
    ansC.GetComponent<BoxCollider>().enabled = true;
    ansD.GetComponent<BoxCollider>().enabled = true;
    if (answer == 2)
    {
        if (ansB == this.gameObject)
        {
            textCanvas.GetComponent<TextMeshPro>().SetText("Correct!");

        } else
        {
            textCanvas.GetComponent<TextMeshPro>().SetText("Helaas,
het goede antwoord is:");
        }
        ansA.GetComponent<TextMeshPro>().SetText("");
        ansC.GetComponent<TextMeshPro>().SetText("");
        ansD.GetComponent<TextMeshPro>().SetText("");
    }
    else if (answer == 3)
    {
        if (ansC == this.gameObject)
        {
            textCanvas.GetComponent<TextMeshPro>().SetText("Correct!");

        }
        else
        {
            textCanvas.GetComponent<TextMeshPro>().SetText("Helaas,
het goede antwoord is:");
        }
        ansA.GetComponent<TextMeshPro>().SetText("");
        ansB.GetComponent<TextMeshPro>().SetText("");
        ansD.GetComponent<TextMeshPro>().SetText("");

    }
    ansA.GetComponent<BoxCollider>().enabled = false;
    ansB.GetComponent<BoxCollider>().enabled = false;
    ansC.GetComponent<BoxCollider>().enabled = false;
    ansD.GetComponent<BoxCollider>().enabled = false;
    // question is answered so next stage

```



```
        Invoke("NextStage", 5);
    }

    private void StageThree()
    {
        if (this.gameObject == next)
        {
            next.GetComponent<MeshRenderer>().enabled = false;
            stageHandler.SetStage();
        }
        else if(!this.gameObject.tag.ToLower().Equals("untagged"))
        {
            textCanvas.GetComponent<TextMeshPro>().SetText(this.gameObject.tag);
        }
    }

    private void NextStage()
    {
        stageHandler.SetStage();
    }
}
```

Appendix 11: AnimationScript.cs

```
using UnityEngine;

public class AnimationScript : MonoBehaviour
{
    private Animator animator;

    // Start is called before the first frame update
    void Start()
    {
        animator = GetComponent<Animator>();
    }

    public void StartAnimation()
    {
        animator.SetBool("startAnimation", true);
    }

    public void SetAnimation(bool start)
    {
        animator.SetBool("startAnimation", start);
    }
}
```

Appendix 12: Reticule.cs

```
using UnityEngine;

public class Reticule : MonoBehaviour
{
    public Pointer m_Pointer;
    public SpriteRenderer m_CircleRenderer;
    public Sprite m_OpenSprite;
    public Sprite m_ClosedSprite;
    private Camera m_Camera;

    public void Awake()
    {
        m_Pointer.OnPointerUpdate += UpdateSprite;
        m_Camera = Camera.main;
    }

    // Update is called once per frame
    void Update()
    {
        transform.LookAt(m_Camera.gameObject.transform);
    }

    private void OnDestroy()
    {
        m_Pointer.OnPointerUpdate -= UpdateSprite;
    }

    private void UpdateSprite(Vector3 point, GameObject hitObject)
    {
        transform.position = point;
        if (hitObject)
        {
            m_CircleRenderer.sprite = m_ClosedSprite;
        }
        else
        {
            m_CircleRenderer.sprite = m_OpenSprite;
        }
    }
}
```

Appendix 13: Pointer.cs

```
using UnityEngine;
using UnityEngine.Events;

public class Pointer : MonoBehaviour
{
    public float m_Distance = 100;
    public LineRenderer m_lineRenderer = null;
    public LayerMask m_EverythingMask = 0;
    public LayerMask m_InteractiveMask = 0;
    public UnityAction<Vector3, GameObject> OnPointerUpdate = null;

    private Transform m_CurrentOrigin = null;
    private GameObject m_CurrentObject = null;

    private void Awake()
    {
        PlayerEvents.onControllerSource += UpdateOrigin;
        PlayerEvents.OnTouchpadDown += ProcessTouchpadDown;
    }

    // Start is called before the first frame update
    private void Start()
    {
        SetLineColor();
    }

    private void OnDestroy()
    {
        PlayerEvents.onControllerSource -= UpdateOrigin;
        PlayerEvents.OnTouchpadDown -= ProcessTouchpadDown;
    }

    // Update is called once per frame
    private void Update()
    {
        Vector3 hitPoint = UpdateLine();

        m_CurrentObject = UpdatePointerStatus();

        OnPointerUpdate?.Invoke(hitPoint, m_CurrentObject);
    }
}
```

```

private Vector3 UpdateLine()
{
    // Create ray
    RaycastHit hit = CreateRaycast(m_EverythingMask);

    // Default end
    Vector3 endPosition = m_CurrentOrigin.position +
(m_CurrentOrigin.forward * 100);

    // Check hit
    if(hit.collider != null)
    {
        endPosition = hit.point;
    }

    // Set position
    m_lineRenderer.SetPosition(0, m_CurrentOrigin.position);
    m_lineRenderer.SetPosition(1, endPosition);

    return endPosition;
}

private void UpdateOrigin(OVRInput.Controller controller, GameObject
controllerObject)
{
    // Set origin op pointer
    m_CurrentOrigin = controllerObject.transform;

    // Is the laser visible
    if(controller == OVRInput.Controller.Touchpad)
    {
        m_lineRenderer.enabled = false;
    } else
    {
        m_lineRenderer.enabled = true;
    }
}

private GameObject UpdatePointerStatus()
{
    // create ray
    RaycastHit hit = CreateRaycast(m_InteractiveMask);

    // check hit

```

```

        if (hit.collider)
        {
            return hit.collider.gameObject;
        }

        // return
        return null;
    }

    private RaycastHit CreateRaycast(int layer)
    {
        RaycastHit hit;
        Ray ray = new Ray(m_CurrentOrigin.position,
m_CurrentOrigin.forward);
        Physics.Raycast(ray, out hit, 100, layer);

        return hit;
    }

    private void SetLineColor()
    {
        if(!m_lineRenderer)
        {
            return;
        }

        Color endColor = Color.white;

        endColor.a = 0.0f;

        m_lineRenderer.endColor = endColor;
    }

    private void ProcessTouchpadDown()
    {
        if (!m_CurrentObject)
        {
            return;
        }

        Interactable interactable =
m_CurrentObject.GetComponent<Interactable>();
        interactable.Pressed();
    }
}

```

Appendix 14: PlayerEvents.cs

```

using System.Collections.Generic;
using UnityEngine;
using UnityEngine.Events;

public class PlayerEvents : MonoBehaviour
{
    #region events
    public static UnityAction onTouchpadUp = null;
    public static UnityAction onTouchpadDown = null;
    public static UnityAction<OVRInput.Controller, GameObject>
onControllerSource = null;
    #endregion

    #region Achors
    public GameObject m_LeftAnchor;
    public GameObject m_RightAnchor;
    public GameObject m_HeadAnchor;
    #endregion

    #region Input
    private Dictionary<OVRInput.Controller, GameObject> m_ControllerSets
= null;
    private OVRInput.Controller m_InputSource =
OVRInput.Controller.None;
    private OVRInput.Controller m_Controller = OVRInput.Controller.None;
    private bool m_inputActive = true;
    #endregion

    private void Awake()
    {
        OVRManager.HMDMounted += PlayerFound;
        OVRManager.HMDUnmounted += PlayerLost;

        m_ControllerSets = CreateControllerSets();
    }

    private void OnDestroy()
    {
        OVRManager.HMDMounted -= PlayerFound;
        OVRManager.HMDUnmounted -= PlayerLost;
    }
}

```

```

    }

    // Update is called once per frame
    private void Update()
    {
        // Check active input
        if (!m_inputActive)
        {
            return;
        }

        // Check if controller exists
        CheckForController();

        // Check for input source
        CheckInputSource();

        // Check for actual input
        Input();
    }

    private void CheckForController()
    {
        OVRInput.Controller controllerCheck = m_Controller;

        // right remote
        if
(OVRInput.IsControllerConnected(OVRInput.Controller.RTrackedRemote))
        {
            controllerCheck = OVRInput.Controller.RTrackedRemote;
        }

        // left remote
        if
(OVRInput.IsControllerConnected(OVRInput.Controller.LTrackedRemote))
        {
            controllerCheck = OVRInput.Controller.LTrackedRemote;
        }

        // update
        m_Controller = UpdateSource(controllerCheck, m_Controller);
    }

    private void CheckInputSource()
    {

```



```

        // update
        m_InputSource = UpdateSource(OVRInput.GetActiveController(),
m_InputSource);
    }

    private void Input()
    {
        // touchpad down
        if (OVRInput.GetDown(OVRInput.Button.PrimaryTouchpad))
        {
            if(OnTouchpadDown != null)
            {
                OnTouchpadDown();
            }
        }

        // touchpad up
        if (OVRInput.GetUp(OVRInput.Button.PrimaryTouchpad))
        {
            if (onTouchpadUp != null)
            {
                onTouchpadUp();
            }
        }
    }

    private OVRInput.Controller UpdateSource(OVRInput.Controller check,
OVRInput.Controller prev)
    {
        // if values are the same, return
        if(check == prev)
        {
            return prev;
        }
        // get controller object

        GameObject controllerObject = null;
        m_ControllerSets.TryGetValue(check, out controllerObject);

        // if no controller, set to the head
        if(controllerObject == null)
        {
            controllerObject = m_HeadAnchor;
        }
    }

```

```

        // send out event
        if(onControllerSource != null)
        {
            onControllerSource(check, controllerObject);
        }

        // return new value
        return check;
    }

    private void PlayerFound()
    {
        m_inputActive = true;
    }

    private void PlayerLost()
    {
        m_inputActive = false;
    }

    private Dictionary<OVRInput.Controller, GameObject>
    CreateControllerSets()
    {
        Dictionary<OVRInput.Controller, GameObject> newSets = new
        Dictionary<OVRInput.Controller, GameObject>()
        {
            { OVRInput.Controller.LTrackedRemote, m_LeftAnchor },
            { OVRInput.Controller.RTrackedRemote, m_RightAnchor },
            {OVRInput.Controller.Touchpad, m_HeadAnchor }
        };
        return newSets;
    }
}

```

References

- Amrein, A. L., & Berliner, D. C. (2002). High-Stakes Testing & Student Learning. *Education Policy Analysis Archives*, 10, 18. doi: 10.14507/epaa.v10n18.2002
- AVRspot. (2018, February 7). Human Eye . Retrieved October 1, 2019, from <https://sketchfab.com/3d-models/human-eye-160c3a0121784ca8a376eac6b55cc56f>.
- Babcock1976. (n.d.) Human Eye Cross Section Eyeball: 3D model. Retrieved October 1, 2019, from <https://www.cgtrader.com/3d-models/character/anatomy/human-eye-cross-section-eyeball>.
- Bashabsheh, A. K., Alzoubi, H. H., & Ali, M. Z. (2019). The application of virtual reality technology in architectural pedagogy for building constructions. *Alexandria Engineering Journal*, 58(2), 713–723. doi: 10.1016/j.aej.2019.06.002
- Charney, J., Hmelo-Silver, C. E., Sofer, W., Neigeborn, L., Coletta, S., & Nemeroff, M. (2007). Cognitive Apprenticeship in Science through Immersion in Laboratory Practices. *International Journal of Science Education*, 29(2), 195–213. doi: 10.1080/09500690600560985
- Cheng, K.-H., & Tsai, C.-C. (2019). A case study of immersive virtual field trips in an elementary classroom: Students' learning experience and teacher-student interaction behaviors. *Computers & Education*, 140, 103600. doi: 10.1016/j.compedu.2019.103600
- Chou, C. C., & Hoisington, D. A. (2018). Promises and Constraints of Virtual Reality Integration: Perceptions from Pre-Service Teachers and K-12 Students. *2018 IEEE 18th International Conference on Advanced Learning Technologies (ICALT)*. doi: 10.1109/icalt.2018.00098
- Christopoulos, A., Conrad, M., & Shukla, M. (2018). Increasing student engagement through virtual interactions: How? *Virtual Reality*, 22(4), 353–369. doi: 10.1007/s10055-017-0330-3
- ClassVR. (n.d.) Create & Plan Your Lessons. Retrieved October 27, 2019, from <http://www.classvr.com/classroom-virtual-reality-lessons/create-plan-school-vr-subjects/>.
- ClassVR. (n.d.). Introducing: The ClassVR Standalone Headset. Retrieved December 15, 2019, from <https://www.classvr.com/school-virtual-reality/student-vr-standalone-headset/>
- Comeau, Z. (2019, October 22). ImmersiveTouch Expands Virtual Reality Surgery Platform To Neurosurgery. Retrieved November 2, 2019, from <https://mytechdecisions.com/video/immersivetouch-virtual-reality-surgery/>.
- Crofton, E. C., Botinestean, C., Fenelon, M., & Gallagher, E. (2019). Potential applications for virtual and augmented reality technologies in sensory science. *Innovative Food Science and Emerging Technologies*, 56 doi:10.1016/j.ifset.2019.102178
- E-learning UMCG. (2017, October 3). Heart after Fontan Procedure. Retrieved October 1, 2019, from <https://sketchfab.com/3d-models/heart-after-fontan-procedure-5d25e5608a7b4bb2a15ea842cdb5b01d>

- Ebers. (2018, December 12). Eye Cross section. Retrieved October 1, 2019, from <https://sketchfab.com/3d-models/eye-cross-section-181bf8e16a8c4ff9bfb6af07ea6c7ff4>.
- Ebers. (2018, December 6). Heart Animated And Bronchial Airways. Retrieved October 1, 2019, from <https://sketchfab.com/3d-models/heart-animated-and-bronchial-airways-a0603576a720436cba99c9f958bf0b14>
- Ebers. (2018, July 16). Eukaryotic Cell Cross Section. Retrieved from <https://sketchfab.com/3d-models/eukaryotic-cell-cross-section-74f714127a8c4211bb1a2cac7195fb1a>
- Gac, P., Richard, P., Papouin, Y., George, S., & Richard, É. (2019). Virtual Interactive Tablet to Support Vocational Training in Immersive Environment. *Proceedings of the 14th International Joint Conference on Computer Vision, Imaging and Computer Graphics Theory and Applications*. doi: 10.5220/0007456201450152
- Gomes, N., Lou, Y., Patwardhan, V., Moyer, T., Vavala, V., & Barros, C. (2019). The Effects of Virtual Reality Learning Environments on Improving the Retention, Comprehension, and Motivation of Medical School Students. *Human Interaction and Emerging Technologies*, 289–296. doi:10.1007/978-3-030-25629-6_45
- Google for Education. (n.d.). Bringing virtual and augmented reality to school. Retrieved December 15, 2019, from https://edu.google.com/products/vr-ar/?modal_active=none
- Google VR. (n.d.). Daydream – Daydream-ready phones. Retrieved December 17, 2019, from <https://arvr.google.com/daydream/smartphonevr/phones/>
- Google VR. (n.d.). Get Cardboard. Retrieved December 16, 2019, from <https://arvr.google.com/cardboard/get-cardboard/>
- Google. (n.d.) Bring your lessons to life with Expeditions | Google for Education. Retrieved October 27, 2019, from https://edu.google.com/products/vr-ar/expeditions/?modal_active=none.
- Innocenti, E. D., Geronazzo, M., Vescovi, D., Nordahl, R., Serafin, S., Ludovico, L. A., & Avanzini, F. (2019). Mobile virtual reality for musical genre learning in primary education. *Computers & Education*, 139, 102–117. doi: 10.1016/j.compedu.2019.04.010
- Jimenez, O. (2016, March 6). Célula humana. Retrieved October 2, 2019, from <https://sketchfab.com/3d-models/celula-humana-cdabc716a88d41908d926109ede7aa4d>
- KageG. (2016, November 23). DNA Animation - Slightly smoother animation. Retrieved October 2, 2019, from <https://sketchfab.com/3d-models/dna-animation-slightly-smoother-animation-11d5d2c5bcf24f0f89b5ea404796f2c4>
- Lee, N. (2019, October 17). The (Day)dream is over: Phone-based VR is well and truly dead. Retrieved December 17, 2019, from https://www.engadget.com/2019/10/16/google-kills-daydream-phone-vr/?guccounter=1&guce_referrer=aHR0cHM6Ly93d3cuZ29vZ2xlMnVbS8&guce_referrer_sig=AQAAAEX1DrMJvwWyoNWXm5g6DN3_kaU_N0Mnw1rmmkew0vjtkMO0S1mxw09g4X29i3HFDdV74-QLwO6cvw9s6V_4FqepEjToxCFNDwZE4KJh1FHBD0DazRstCoTOMDfKiYey1um4PmqQNaG6RayGOrRHapmTEReDcETfnk9nJNMTx1oq

- Lenovo. (n.d.). Introducing the Lenovo VR Classroom. Retrieved December 16, 2019, from <https://solutions.lenovo.com/vertical-solutions/k-12-education/vr-classroom/>
- Lenovo. (n.d.). VR Classroom - Lenovo K-12 education. Retrieved December 16, 2019, from <https://solutions.lenovo.com/vertical-solutions/k-12-education/vr-classroom/#vr-classroom-kit-includes>
- Madsen, S. (2020, January 7). Using the MoSCoW Method to Prioritize Projects. Retrieved December 16, 2019, from <https://www.projectmanager.com/training/prioritize-moscow-technique>
- Sauro, J.. (2011, February 2). Measuring Usability with the System Usability Scale (SUS). Retrieved January 2, 2020, from <https://measuringu.com/sus/>
- System Usability Scale (SUS). (2013, September 6). Retrieved January 4, 2020, from <https://www.usability.gov/how-to-and-tools/methods/system-usability-scale.html>
- Merchant, Z., Goetz, E. T., Cifuentes, L., Keeney-Kennicutt, W., & Davis, T. J. (2014). Effectiveness of virtual reality-based instruction on students learning outcomes in K-12 and higher education: A meta-analysis. *Computers & Education*, 70, 29–40. doi: 10.1016/j.compedu.2013.07.033
- Merchant, Z., Goetz, E. T., Keeney-Kennicutt, W., Kwok, O.-M., Cifuentes, L., & Davis, T. J. (2012). The learner characteristics, features of desktop 3D virtual reality environments, and college chemistry instruction: A structural equation modeling analysis. *Computers & Education*, 59(2), 551–568. doi: 10.1016/j.compedu.2012.02.004
- Microsoft Education. (n.d.) Paint 3D in the Curriculum. Retrieved October 28, 2019, from <https://education.microsoft.com/courses-and-resources/resources/3d>.
- Microsoft. (n.d.) Mixed Reality voor het onderwijs. Retrieved October 28, 2019, from <https://www.microsoft.com/nl-nl/education/mixed-reality>.
- MotionCow. (2016, December 31). Eye Anatomy. Retrieved October 1, 2019, from <https://sketchfab.com/3d-models/eye-anatomy-5dac474887174eb78cb7ffce6bd9ce3a>.
- Neural Impulse Media. (2016, May 22). Arterial vessel tour . Retrieved October 1, 2019, from <https://sketchfab.com/3d-models/arterial-vessel-tour-246576050a644cb4ae16840922385e39>
- Samosorn, A. B., Gilbert, G. E., Bauman, E. B., Khine, J., & Mcgonigle, D. (2020). Teaching Airway Insertion Skills to Nursing Faculty and Students Using Virtual Reality: A Pilot Study. *Clinical Simulation in Nursing*, 39, 18–26. doi: 10.1016/j.ecns.2019.10.004
- Samsung. (n.d.). Gear VR voor Samsung Galaxy S6 en Galaxy S7. Retrieved December 17, 2019, from <https://www.samsung.com/nl/wearables/gear-vr-r322>
- Scherer, R., Siddiq, F., & Tondeur, J. (2020). All the same or different? Revisiting measures of teachers technology acceptance. *Computers & Education*, 143, 103656. doi: 10.1016/j.compedu.2019.103656
- Spicer, M. A., & Apuzzo, M. L. (2003). Virtual Reality Surgery: Neurosurgery and the Contemporary Landscape. *Neurosurgery*, 52(3), 489–498. doi: 10.1227/01.neu.0000047812.42726.56
- Stepan, K., Zeiger, J., Hanchuk, S., Signore, A. D., Shrivastava, R., Govindaraj, S., & Illoreta, A. (2017). Immersive virtual reality as a teaching tool for neuroanatomy. *International Forum of Allergy & Rhinology*, 7(10), 1006–1013. doi: 10.1002/alr.21986
- Teslenko, O. (n.d.). What are the technologies used in AR/VR/MR? Retrieved December 17, 2019, from <https://wear-studio.com/what-are-the-technologies-used-in-ar-vr-mr/>

- Transcription / DNA transcription. (n.d.). Retrieved October 1, 2019, from <https://www.nature.com/scitable/definition/transcription-dna-transcription-87/>
- Understanding the Structure of the Eye - Lesson. (2019, July 2). Retrieved December 17, 2019, from https://www.teachengineering.org/lessons/view/clem_waves_lesson05
- Vergara, D., Rubio, M. P., Lorenzo, M., & Rodríguez, S. (2019). On the Importance of the Design of Virtual Reality Learning Environments. *Methodologies and Intelligent Systems for Technology Enhanced Learning, 9th International Conference*, 146–152. doi:10.1007/978-3-030-23990-9_18
- Vertemati, M., Cassin, S., Rizzetto, F., Vanzulli, A., Elli, M., Sampogna, G., & Gallieni, M. (2019). A Virtual Reality Environment to Visualize Three-Dimensional Patient-Specific Models by a Mobile Head-Mounted Display. *Surgical Innovation*, 26(3), 359–370. doi: 10.1177/1553350618822860
- Viar360. (2019, July 17). About the product: Immersive & interactive 360 VR content. Retrieved November 2, 2019, from <https://www.viar360.com/product-features/>.
- What is DNA replication? (2016, January 25). Retrieved October 1, 2019, from <https://www.yourgenome.org/facts/what-is-dna-replication>
- What is MoSCoW Prioritization?: Overview of the MoSCoW Method. (n.d.). Retrieved December 16, 2019, from <https://www.productplan.com/glossary/moscow-prioritization/>
- Zorzal, E. R., Sousa, M., Mendes, D., Anjos, R. K. D., Medeiros, D., Paulo, S. F., ... Lopes, D. S. (2019). Anatomy Studio: A tool for virtual dissection through augmented 3D reconstruction. *Computers & Graphics*, 85, 74–84. doi: 10.1016/j.cag.2019.09.006