Utrecht University

The effects of augmented reality on concept development of girls in secondary education

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Augmented reality, flipping the classroom, intrinsic motivation, self-determination theory, situated learning, collaborative learning, informal learning, meaningful learning, higher- order thinking skills.

Abstract

The educational value of augmented and virtual reality has been extensively theorized about, and practical studies have been performed (Wu et al, 2013). This small-scale preliminary research analyzes the effects of augmented reality (AR) on the concept development about the digestive system of girls of the Dutch lower secondary education system (3HAVO).

This research used a pre and post survey with worksheets. The test of the nutrition and digestion chapter completed by the 29 participants, and an interview with five students from class 3C from the Cornelius Haga Lyceum. The participants were all girls because the majority of students in this school are girls and classes are divided by gender. Students used an AR app on a Samsung tablet to observe the chemical digestion of food. This app was developed by Utrecht University under the name Human Digestive System (HDS). The results were analyzed as a whole sample from the pilot class 3C. Participants showed positive progress in concept development regarding nutrition and digestion. When using the app, students showed increased motivation, collaboration and higher order thinking skills (HOTS) (Yen et al., 2015). Participants who used AR in the classroom also achieved better results on the test of nutrition and digestion.

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Introduction

Students, especially girls, in grade three have trouble with the visualization of abstract concepts in the subject of biology (Meerah, 1998). The visualization problem especially applies to the chapter on nutrition and digestion, because this material requires more insight and comprehension in understanding the chemical processes than the other subjects in biology. One reason why students have limited insight into this subject is due to the fact that students are unable to put certain concepts on the retina and have no idea what the concepts means. In specific, in the chapter nutrition and digestions it is expected that students can visualize the image they have formed with certain concepts in other topics in biology. This visualization problem leads to confusion about concepts in biology, preventing students from mastering the material and progressing in the curriculum. For example, if students have to describe enzymes, they cannot visualize that enzymes work specifically for a substrate and can, break down nutrients. Students see enzymes as a separate part of the whole in the human body, where a single enzyme can break down all nutrients.

Visualization of abstract concepts is important for understanding biological processes, such as protein synthesis and compound cycles. Understanding biological processes also requires other skills, such as spatial abilities and visual working memory capacity.

Visualization is closely related to intrinsic motivation and learning (Rieber, 1995; Leutner, 1993; Neal, 1990). This means that learning output can be increased if students can visualize certain concepts or phenomena. Recent studies in the field of digital didactics indicate that new visualization techniques, such as AR, will allow students to visualize abstract concepts that are invisible to the human eye, like DNA, and the digestive system.
AR establishes a direct relationship between the virtual and physical environment that helps students understand difficult concepts in a rich interactive learning environment. This could lead to stimulation of concept development (Hay et al., 2000) and the visualization of abstract concepts. AR may therefore be a solution to visualize the abstract concepts better by the girls. This is the reason for the research question of this study: *Does the use of AR positively influence conceptual development about the understanding of the digestive system improve in girls at the lower secondary education level?*

1. Theoretical background

1.1 Augmented Reality

Augmented Reality is a technology that adds virtual elements to the real world. Therefore AR products allow users to perceive and interact with virtual constructs. This creates a sense of presence, meaning users feel they are present in this artificial reality.

AR is described in the literature in several ways. According to Specht (2010), AR is "An area of computer research that is about the combination of the real world and the data generated by computers." Robert Rice on the other hand, gives a broader description of AR:

"When I talk about Augment Reality, I try to expand the definition a bit. Usually when you talk to people about Augmented Reality, projecting a 3D environment on top of video is the first thing that comes to mind. However, I think it would be better that it would be about any form of media that enriches or enhances your specific reality through context " (De Lange et al., 2017).

An example of AR is shown in Figure 1. The smartphone app shows how carbohydrates are processed in the digestive system on a molecular level. The phone's camera is used to show the reality from the picture and the HDS app projects an image on top of it.

Figure 1. The Human Digestive System app

An AR device contains additional sensors that register user interaction with the real world. This data is processed and interpreted by the device and determines how simulated objects are displayed in the real space. The device can reflect the image of any real object in the interactive environment.

AR was first developed and used in 1960 (Johnson, Levine, Smith, & Stone 2010). The designer used an optically transparent head-mounted display in combination with a mechanical or ultrasonic tracker. Due to the limited processing capacity of computers at the time, only simple wireframe drawings could be displayed in real time (Sutherland, 1968). Since then, a large number of institutions, including schools have used AR for visualization, training and other purposes. This technology offers many opportunities for education, which is why AR has received significant attention in international science and technology in recent decades. Scientists have called this revolution the augmented-reality revolution (Lee et al,2012).

In addition to AR, virtual reality (VR) is also on the rise. AR differs from VR in that AR combines the real world with computer graphics, while VR engages the user in an entirely computer-generated world.

Earlier research on the effect of visualization techniques looked at animation, virtual environments and stimulation. Dede et al. (1996) suggest that students can improve their learning capabilities of abstract concepts by using virtual environments designed for learning purposes. Robertson et al. (2008) discovered that animation combined with interesting data and an exciting presenter helps people understand the information.

These visualization technologies can be used to address the visualization problem of students, especially in the abstract sciences, and help students understand the material. In this context, Utrecht University has developed an AR app called Human Digestive System, which focuses on the chemical digestion of food in the digestive system. Through visualization techniques, students feel like they are traveling through the digestive system and learn the concepts that are important in chemical digestion, such as proteins, carbohydrates and amino acids.

1.2 Operation of an augmented reality device

The user of AR devices sees both natural and synthetic world. This is achieved by projecting computer images onto either eyeglasses through which natural light passes.

Advanced AR devices include the Microsoft Hololens. This lens uses an accelerometer (to measure the speed of head movements from the user), a gyroscope (to record the tilt of the user's head) and a magnetometer (to measures which direction the user's head is pointing) to offer users the best possible experience. The Hololens contains mirrors that are used to help the way the eye does it view projected virtual image. The Hololens' mirrors include transparent holographic lenses that use an optical projection system that projecy holograms into the user's eyes. A light motor transmits the light to two separate lenses, one for each eye, which consist of three glass layers for the three primary colors. The light touches those layers and enters the eye at specific angles, intensities and colors to produce an image on the retina. The devices are controlled through voice commands or touch pads. The latest augmented reality devices are wireless and therefore more user-friendly than devices before(Reality Technologies, 2016) (Porter & Heppelmann, 2017).

1.3 Advantages and disadvantages of using AR in lessons:

The advantages that AR can offer teaching practice and learning are recognized by several researchers. It can help students visualize complex spatial objects (Arvanitis et al., 2007) and interact with three-dimensional synthesized objects in mixed reality (Kerawalla, Luckin, Seljeflot, Woolard, 2006). Klopfer (2008) stated that the educational benefits of AR, a new platform, have not been thoroughly investigated. Rochelle and Pea (2002) mention that teachers use existing educational software to fundamentally reconsider whether the educational area will benefit from handheld technologies. Now let's look at the benefits of AR in education.

Klopfer, Squire, Holland and Jenkins (2002) list five benefits of in education:

- Stimulating the Higher order of Thinking Skills: AR encourages students to use knowledge at various levels such as (analysis / reasoning / applying).
- Social interactivity: The devices can exchange data between different users, which leads to cooperation between the students.
- Autonomy: It stimulates the students to work more independently. The device provides customized information based on what the user wants to do.

- Critical thinking: it stimulates students to look up information more critically and to assess it themselves.
- Collaborative learning: This term refers to an instruction method in which students at various performance levels work together in small groups toward a common goal. The students are responsible for one another's learning as well as their own. Thus, the success of one student helps other students. Proponents of collaborative learning claim that the active exchange of ideas within small groups increases interest among the participants and promotes critical thinking. According to Johnson and Johnson (1986), cooperative teams achieve higher levels of thinking and retain information longer than students who work quietly as individuals. Shared learning gives students an opportunity to engage in discussion and take responsibility for their own learning, thus becoming critical thinkers (Totten et al., 1991)

AR can enhance the learning experience by creating synthetic 3D objects students can work with. For example, students can use the 3D synthesized objects to the increase their own visual perception by observing 3D objects from different perspectives (Hsin-Kai Wu, Silvia Wen-Yu Lee, Hsin-Yi-Chang, Jyh-Chong Liang, 2013). Several studies also show that AR plays a positive role in studying a new unknown subject. Kerawalla, Luckin, Seljmflot and Woolard (2006) investigated the use of AR in an astronomy lesson. One group used AR to observe the rotation of the earth around the sun and the other group used books and physical objects. The researchers analyzed the questions asked by teachers in the two groups and interviewed the teachers afterwards and found that using AR helps make difficult topics accessible.

AR can also be used to visualize unobservable phenomena, such as gravity, magnetic fields and waves, airflow and forces, using virtual objects such as vectors, symbols or molecules in the human body projecting. In chemistry, for example, students use AR to see chemical elements and self-assembled and rotated 3D molecular models (Fjeld & Voegtli, 2002).
Clark, Dünser and Grasset (2011) enriched a paper-based coloring book for chemistry with 3D content and offered children a "pop-up book experience" by visualizing the 3D models.

Besides, that AR has an influence to visualize certain phenomena, it also contributes to stimulating research skills. A pedagogical experiment investigated the effect of a virtual analytical lab on the student research skills. Student results were compared in two learning environments. The traditional group (control group) learned the skills in classroom setting and the experimental group learned online in combination with personal learning. The effectiveness of the virtual lab was tested based on students’ reports, and the groups were compared based on 10 established criteria. The study showed that working with the virtual lab improved practical and research skills more than learning the traditional way (Bortnik et al., 2017).

In addition, other striking findings have been found about the use of AR in the virtual lab.
Rosenbaum et al. (2007) showed that students' sense of authenticity about dynamic models and complex causalities improved using AR environments. Additionally, Sotiriou and Bonger (2008) showed that using AR increases students’ motivation and interest, which leads to improved research skills and more knowledge on the subject. Hsin-Kai Wu et al. (2013) show that AR can also improve psychomotor cognitive skills, because both haptic and visual directions can be used. In addition, AR systems offer solutions for learning difficulties, in particular the visualization of non-visible phenomena such as proteins in the human body.

However, in addition to the benefits mentioned, there are also drawbacks to using AR in class. Researchers also found technological problems. According to Kerawalla et al. (2006), most types of AR technologies have a head mounted display, often with a backpack for computer equipment, which can be inconvenient and cause poor depth perception. Squire and Jan (2007) found that without well-designed protocols or interfaces to navigate student actions, students have difficulty interpreting the directions in the devices, recognizing the flow of information from one device to another, and navigating between reality and fantasy. Additionally, GPS errors cause frustration among students and were mentioned by teachers as problematic. However, some of these technological problems are already being overcome by progress in AR systems. AR can now be used wirelessly and the technology is becoming increasingly sophisticated.

Researchers also emphasize pedagogical aspects that must be taken into account. Like many educational innovations, AR faces resistance from schools and teachers (Hsin-Kai Wu et al., 2013). IT significantly changes the way of teaching, which is currently teacher-centric. A gap may arise as a result of a study between the teaching and learning methods currently used in lessons and the student-oriented of AR systems.

Developers of AR systems must bridge the gap and help teachers change their teaching method to use AR in the lessons.

Finally, researchers found challenges regarding students' learning process. In AR learning environments, users can be cognitively overloaded with the huge flow of information, the multiple technological devices that they need use and the complex tasks they perform. Research has shown that students often felt overwhelmed and confused when they worked with AVR systems due to the unknown technologies with complex tasks. In addition, operating in AR environments requires students to apply multiple complex skills in spatial navigation, collaboration, problem solving, technology manipulation and mathematical estimation (Dunleavy et al., 2009). These are the very areas AR is supposed to improve (Kerawalla et al., 2006; Hsin-Kai Wu et al., 2013). In addition, Dunleavy et al. (2009) state that information confusion may arise among learners about the distinction between the real and virtual world. This can reduce the effectiveness of the lesson and even threaten the physical safety of pupils.

1.4 Educational potential of augmented reality

Dede (2009) confirmed that using AR to visualize abstract concepts is effective due to several factors. First, visualization technologies make phenomena visible that are too small, large, fast or slow to see with the naked eye (Cook, 2006). For example, Stith (2004) used software to create an animation of enzyme-substrate binding for teaching cell biology. Second, AR provides the opportunity to study almost all information in a context that enhances learning, for example, virtual field trips (Minocha et al., 2018). This enhanced learning is based on an older concept of situated cognition, which states that learned knowledge cannot be fully abstracted from the context in which it is learned and used (Brown et al., 1989). This means that knowledge taught in a classroom is inevitably affected by the school culture. The third factor is transfer of information. This factor is intertwined with situated learning. By teaching students information in a situated learning context that mimics the real-life context, the amount of transfer required to apply what has been learned to the real-world is significantly decreased compared to learning it in a disjointed context, such as a traditional classroom (Mestre, 2002).

Finally, Bakri et al. (2019) show that AR can contribute to stimulating the higher-order thinking skills. HOTS is a concept popular in American studies that distinguishes critical thinking skills from low-order learning outcomes, such as those attained by rote memorization. HOTS include synthesizing, analyzing, reasoning, comprehending, application, and evaluation. To achieve a strong conceptualization process, these skills must be encouraged.

In conclusion, AR offers many opportunities in education, mainly helping students gain knowledge, in particular in the abstract and non-visual field, by using new learning methods. AR has several positive effects on educational outcomes. There are still technological, pedagogical and other challenges for AR to become a successful tool for education. In addition, the high costs and limited teaching material are an obstacle to educational institutions using AR. More research is needed on the effect of AR on education.

2. Methods

2.1 Description

This study used small scale preliminary qualitative and quantitative research in the third grade of HAVO, performed in seven steps (see Table 1). The selection of participants, dissemination and design of the survey and the worksheets and how the results were analyzed are discussed in this chapter.

Step	**Research part**	**Participants**
Step 1	Literature review	
Step 2	Pre-survey	Class 3C
Step 3	Experiment with Worksheets and use of AR	Class 3B and 3C
Step 4	View lesson recordings	Class 3C
Step 5	Interviews	Class 3C
Step 6	Examination of the chapter on nutrition and digestion	Class 3B and 3C
Step 7	Post survey	Class 3C

Table 1. Overview of the steps

2.2 Participants

Two female classes from the Cornelius Haga Lyceum were used for this study: 3B and 3C. There were 29 girls in both classes.

Class 3C was the pilot class; its fifteen students were the main participants of this research. The 14 students in the control class (3B) answered the questions in the worksheets and took the test on the nutrition and digestion chapter to compare to the results with the pilot class (3C). Parents' permission was requested in writing to use these students for this research and to film or photograph them.

Step 1. Literature review

To examine the educational impact of AR in secondary education, articles were collected via Google Scholar and World Cat using the following search concepts: augmented reality, virtual reality, flipping the classroom, intrinsic motivation, self-determination theory, behavior, constructive, situated learning, collaboration, informal learning, meaningful learning, higher- order thinking skills. Other references were also accessed, such as reports that measured the effects of AR in secondary education.

The keyword search resulted in fifty papers in English. These were narrowed down based on the inclusion criteria: peer-reviewed articles, English articles, and articles between 2007 and 2019. This last criterion is important because AR technologies were only applied after 2007 in education.

Based on the literature research, a research framework was developed, where new insights in the field of digital didactics (i.e. AR) led to certain ideas for this research, such as their implementation of AR in the classroom.

Step 2. Conducting a pre-survey

The full survey can be found in Appendix 1 in Dutch. It was created using the information on successful survey design from Brace (2018). It consists of twenty multiple choice questions in three sections to measure students' prior knowledge about chemical digestion of nutrients. To monitor students' progress, questions were developed on the worksheet with the help of the information from the pre-test

A pre-survey was conducted via Google Forms. This online tool was selected because it allows the survey to be accessed with a link that can be plugged into a mass email. This allows participants to access it without providing any personal information, thus preserving their anonymity. Data analysis was conducted using SPSS statistics.

The girls from the pilot class 3C took the pre-survey, which first asked them to give their class and email-address. They were then reminded not to press themselves too hard when answering certain questions. The first section (questions 1–5) is about how the students interpret the concepts. The second section (questions 6–10) is about the function of the concept. The third section (questions 10 – 20) is about interpreting the concept in different contexts within the function from the concept.

The pre-survey was given at the start of the study, and showed which concepts students' most struggled with. This information was used to develop the questions on the worksheets, and students could practice those concepts using the app and the worksheet.

Step 3. Experimtent in class 3C with worksheets and AR

In class 3C HAVO, the HDS app was use in two Samsung tablets during October–December. The class was divided in two groups, and this group, class 3C consisted of fifteen students. The students received a worksheet with questions to get started. Students from class 3C were given 45 minutes per lesson during the chapter nutrition and digestion to work using this tablet. The students were allowed to work on these questions together on the worksheet. The groups were formed by the students themselves.

After a brief instruction, the students formed groups within fifteen minutes. A successful attempt was made to let strong and weak students work together. This increased the differentiation during these lessons, and led to different Higher Order Thinking Skills being stimulated during these lessons.

To use AR in the classroom in a responsible manner, worksheets were developed for the students in class 3C. Besides that, the worksheet also included questions about the concepts that the students had difficulty with (see **Appendix 2A**). The worksheets included questions that had to be answered with the information from the app, textbook and their mobile phone. These questions were written with the help of Bloom's taxonomy, which stimulates students' higher order thinking skills. The worksheets were used as a formative test. Various studies indicate that formative test improves learning (Shepard et al., 2005). These worksheet are given in **Appendix 3A**.

The questions 1 till 9 are used to interpret the concepts, for example, by naming a function of a term or writing the name of the term with a description. This fits in with Bloom's taxonomy: remembering, understanding, applying and analyzing. Question 10 asked students to fill in a table about which substance is related to that concept using the HDS app and textbook. This fits in with Bloom's taxonomy: analysis and creation.

Step 4. Lesson recordings

The lessons in class 3C in which AR was used were filmed. These recordings were viewed by the researcher to evaluate and improve the application of AR in the lessons. The observation tool used for this analysis is included in Appendix 4 and consists of components such as education focused on collaborative learning, higher order thinking skills, social activity, feedback, intrinsic motivation from the students, use of ICT and attitude of students.

The lessons were recorded with a video camera. At the end of the lessons, the students' behavior was evaluated with an evaluation form (see **Appendix 4)** by the researcher to determine the pedagogical effects of AR. The student's behavior, intrinsic motivation, cooperation, higher order thinking skills and differentiation at level were considered.

Step 5. Interviews with students

Semi-structured interviews were held with four students aged 15–16 in class 3C. Semi-structured interviews were used because they provide structured answers and allow interviewees to elaborate on answers and provide more specific information (Verhoeven, 2018). The following themes were discussed: application of AR, advantages and disadvantages of AR, the effect of AR on intrinsic motivation, challenges of AR, learning outcomes, interactive learning, independent learning, understanding, and visualization with and without AR. The themes from the interview were validated in a previous study on the use of AR in education (Vyncke, 2019).

The interviews were held in a biology class at the Cornelius Haga Lyceum. The interviewees were interviewed one at a time. The interview opened with a brief introduction that set the stage and the reactions for participants. Data collected in studies where participants give first reactions was reported to be most stable (Tourangou, Rips, Rasinski, 2000). The program Speechy was used to translate voice into text. Each interview lasted approximately thirty minutes. These interviews were recorded with the permission of the interviewees to better analyze the answers afterwards. The questions focused on collecting information about using AR in the classroom. Only information that was strictly necessary for this research was asked about. Part of an interview is given in **Appendix 5.**

Step 6. Results of the test: Nutrition and digestion in class 3B and 3C

The test was taken from the biology method used by the school: Biologie Voor Jou. This included questions in which the concepts of the chapter on nutrition and digestion were tested. For data analysis, the results of class 3B and 3C of the nutrition and digestion test were processed using SPSS. Subsequently, the data were analyzed using an independent sample t-test, as this test is suitable to compare the two groups that are subject to different conditions.

Step 7. Conducting a post-survey

The final step in this study was a post-survey. This was only given in the pilot class 3C. The post survey was presented in the same way as the pre-survey using Google Forms.

The post-survey measured the effect of AR on concept development about chemical digestion (see **Appendix 2B).** The same sections and concepts from the pre-survey were asked about using different questions and contexts. The findings of the post survey are described in Chapter 3. Both surveys (pre and post) consisted of eighteen multiple choice questions and three open questions. The questions in both the pre- and post-survey were given a weight that reflected the difficulty of each question. The difficult questions received a value of 5, and the easy questions a value of 0. Five difficult questions were used. The difficult questions were mainly ones where the students had to explain or visualize the concepts about chemical digestion. The findings of the post survey are described in Chapter 3.

2.3 Data analysis

The data analysis was split into three parts, the first being an analysis of the results of the pre test. The difficult questions were presented in a bar chart for the descriptive analysis of the students' answers in both the pilot class (3C) and the control class (3B). The five difficult questions with the rating 5 are included in the worksheet for students in HAVO 3. These findings are further described in Chapter 3.

The second part of the data analysis where the interviews with the students in class 3C. The interviews were analyzed using the speech program Speech. Relevant text fragments containing valuable information from the interviews with the students have been selected using this speech program. After the interview has been transcribed, the results have been transcribed. The entire interview was reread for each student and certain labels (codes) were placed, such as: Concepts / Motivation / Visualization / Insight / Challenging, etc.

The text fragments are first encoded openly. These codes were then compared with each other and the corresponding codes were grouped together within an umbrella code, after which the main categories, such as: the effects of AR on the concept development by the girls, emerged that led to the results and the conclusion for this study. The program: Atlas.ti was used for coding.

Finally, a final exam on the chapter on nutrition and digestion was used to analyze the results of the girls in both classes. The results of the exam were analyzed using an independent paired sample test in SPSS. The test also consisted largely of questions that related to the concepts of the main nutritional and digestion. The results of the exam were analyzed using an independent paired sample test in SPSS.

The learning objectives from the chapter nutrition and digestion were also analyzed from both classes during this phase. The results of this statistical test are used in Chapter 3 to answer the research question.

3. Results

3.1 Pre-survey

The information from the pre-test presents that in the pre-test there are 3 most incorrectly answered questions that attract attention within this chapter. The pre- and post-test will focus on these three questions. These contain concepts related to the visualization of the abstract concepts for the chapter nutrition and digestion.

The pre-test showed that students have difficulty visualizing the concepts proteins, enzymes, and nutrients, as questions 6–9 are most incorrectly answered questions. Question 6 asked students to recognize a protein structure from an image percentage was 5% answered correctly, questions 7 asked students to name the function of an enzyme percentage answered this question correctly was 10% and question 8 the breakdown of nutrients percentage answered this question correctly was 10%, and at last question 9 asked students the location of a specific enzyme production in the digestive system, percentage answered this question correctly was 20%. This means that students find it difficult to visualize the abstract concepts within the chapter nutrition and digestion.

3.2 Post survey

The post survey showed clear improvement, especially on questions 6–9. The percentage that this question was answered incorrectly was reduced. In addition, the girls also scored better in the post test on the questions where they had to recognize a concept based on an image.

These data show that questions 6,7,8 and 9 were answered better than the pre-test. Students have the concepts: "proteins," starch, and "nutrients". Better answered.

Question 6 was answered 65% better. Question 7 was answered 30% better, question 8 was also answered 30% better and finally question 9 was answered 40% better compared to the pre test.

After taking the post survey, the girls were asked to evaluate using AR in the lessons. Their answers showed that using AR helped them visualize abstract concepts in the chapter on nutrition and digestion, which led to students better understanding the material in this chapter. This means that AR has an important influence on the concept development among girls in class 3C HAVO.

3.3 Worksheets

The different answers of both groups (AR group and control group) are displayed in **Appendix 3B**. Students in class 3C better answered the concepts of naming the position or the name of a term with the help of AR than those in class 3B. Additionally, students who did not use AR did not fill in the table where they were asked which substance is broken down in which digestive organ, while the AR group did **(see Appendix 3C).**

3.4 Lesson recordings

Students in the AR class participated more actively compared to the control class. This was shown by the students using information from various sources from their own initiative and sharing it in their own group. The students also asked each other questions.

The conversations between students showed that the strong and weak students worked together effectively to look up answers, for instance using a mobile phone or a textbook. This was striking, because students are usually a more passive in developing new knowledge in a difficult chapter. Figures 2 and 3 show images of a few moments during one of these lessons in the AR class.

Figure 2. Moment during class

Figure 3. Moment during class

In addition, the Higher Order of Thinking Skills (HOTS) became also clearly visible in the lessons where AR were used. These are explained below.

- Memory: The students from class 3C remembered and stored information better than class 3B: during the sessions the teacher explained concepts such as enzymes, starch, carbohydrates, and nutrients, and the student could name them in the test from the chapter nutrition and digestion. Both the test and the answers from the worksheet showed that the students gained knowledge gained about these concepts.

- Understanding: The students from class 3C better understood the concepts and can explain the concepts from the chapter nutrition and digestion to each other during the lessons. While collaboratively answering the worksheet questions, students discussed the connections between the various organs and the digestive juices. For example, one of the students said: "*Oh, so starch is first broken down into glucose before it is absorbed by the body." While the other student said: "I can visualize now the chemical digestion better with this app."*
- Apply: The students from class 3C could use the knowledge from the chapter nutrition and digestion in new situations, for example, the teacher explained chemical digestion and the student can describe this process in different contexts. This provides meaningful learning, which means that AR help students to connect better with the living environment and provides meaning to the newly formed knowledge.
- Analyze: the students from class 3C demonstrated logical thinking and the ability to see connections between information. In this study, this involved using different sources (a tablet, textbook and phone) to gather information about chemical digestion during the lessons. They explained the material to each other and tried to extract the most important information from this source. The ability to better analyze data is a striking phenomenon that was reflected in the answers given on the worksheet and the mutual conversations between the students.

3.5 Interviews

The interviews showed that students gain more insight into difficult concepts by using the AR app HDS. According to the interviewees, this was because they can visualize the abstract concepts better using the visualization techniques in the HDS app. Students indicated that these concepts are often unclear in the textbook, and the illustrations do not always provide clarification. The interviewees provided the following answers to the question whether they can visualize the concepts through the images in the textbook:

"I actually think the book does not explain a term adequately." The concepts are not explained clearly in a textbook. The connection between a picture and a description of the term is usually missing.

"I can't visualize that term with just an image." The students find it difficult to visualize the concepts through an image only. They need more to understand those concepts, for example, moving images.

"When I look at a picture I don't see a clarification of that concept." An image does not necessarily provide clarification, and can even cause confusion.

"I actually learn the concepts by *heart* without being able to imagine them." Memorizing concepts means the students are less likely to understand them in other contexts, so meaningful learning is missing.

The interviewees stated that using AR helped them visualize concepts, which can contribute to further concept development. The students produce visual descriptions when asked about what they think about using AR. These are examples of their responses: "It seems like I'm in the intestinal tract" and "I just felt like a protein."

The students recommended developing a similar app for their level of learning for all chapters in their biology lessons. They believe this technology has added great value for biology education.

As mentioned before in Section 3.3, the students collaborated. The interviewees stated that this led to a better learning yield than their regular education methods.

3.6 Test work

The analysis of the exam results for the chapter on nutrition and digestion in class 3 clearly showed that the students who had used the HDS app had scored higher than those who had not. Therefore, AR has a positive influence on learning performance.

The test results (table 2) show a significant difference between the grades from class 3B and 3C. Class 3C achieved a class average of 7.2 for the exam on the chapter on nutrition and digestion, compared to 6.6 for the control class.

To determine whether a difference between the test results is based on chance, an independent sample t-test was used to determine the p-value. Table 2 shows the results. The p value (Sig.) is 0.001., meaning the differences in the results are not by chance, as this value is lower than 0.05 (5% chance of error).

Cornelius Haga Lyceum	Mean Difference (I-J)	Std. Deviation	Std.Error mean	95% Confidence Interval		t	df	Sig. (2-tailed)
				Lower Bound	Upper Bound			
PW: Voeding en Vertering	-.5478	1.7634	.1644	-.8736	0.2221	-3.332	29	0.001

Table 2. Difference in test results from the chapter nutrition and digestion in class 3B and 3C.

There was also a qualitative difference between the exam results of the two classes. The girls in the pilot class gave more profound answers to the questions where they had to reproduce or describe concepts, such as enzymes, starch, carbohydrates, and nutrients. In addition, they were better able to explain the process of chemical digestion and showed more insight into the material. From the test results it can be concluded from the results of the test that class 3C has achieved all the learning objectives of the chapter nutrition and digestion, while class 3B has not achieved all of these.
The exam results confirm that using AR has a positive influence on the learning performance.

4. Future perspective

AR has the potential to meet the broadest educational objectives, which was confirmed by this study on biology lessons about the digestive system. The improvement of concept development and stimulation of collaborative learning during the lessons are important examples of this.
The benefits of using AR in education can be further enhanced if a coherent AR system is designed for multiple scientific areas, such as chemistry and biology. The combination with other technologies, such as VR, also requires further development. Further research in the field of chemistry and biology can lead to more insight into the demand for integrated education in various fields.
Copolo and Hounshell (1995) showed that students who used both computer and physical models in a group performed considerably better than the groups that only used one of the two models. Additionally, Wu, Krajcik and Soloway (2001) concluded that both computer and physical models "Must be offered through classroom instruction," because within a group, students have individual preferences for different types of models and symbol systems. Further empirical research about implementing AR in the classroom is required for further analysis.
To maximize the benefits of AR in education, it is important to investigate how it can be tailored to different educational approaches in order to achieve educational objectives. For example, the effect of AR by gender, grade, and target groups within secondary education should be studied. The schools for secondary education could also create opportunities for students and teachers to come up with additional uses for AR. For example, a profile assignment where students are asked to give their ideas about using AR in various grades could give more insight into how AR can be used effectively. Furthermore, teachers could be given opportunities to develop apps, for example, by creating vacancies from DUO (service implementation) where the teachers can combine this part-time function with their current job.

5. Discussion

In addition to the aforementioned benefits of using AR in education, there are also several pedagogical issues that need to be taken into account when AR is implemented in the classroom.

1 Like previous educational innovations, using AR in classrooms can be challenging due to school limitations and teacher resistance. For example, the introduction of AR might conflict with school policy, which can lead to a divided vision within the school about implementation. In addition, a limited technical knowledge of teachers can complicate implementation.

2 There are subject-specific limitations like time pressure and the planning of the curriculum of the subject in question.

3 There may be a gap between the teaching and learning methods currently used in the physical classrooms and the student-centered and exploratory nature of learning used in the AR systems. This gap can be filled with the following suggestions for improvement.

   a. Designers of AR learning environments should be aware of that gap during the design process and they need to provide support to help teachers and students bridge the gap. Teachers and students will not understand quickly how to use AR. Since there is no manual for using the app, the teacher will have to explain in class and guide students in the process. This must be taken into account in class preparation. This problem is also recognized by Folkestad and O'Shea (2011), whose participants indicated that they were frustrated when using the technology outside and always had to ask their teacher for help. The results indicated that, despite technical problems, the students found the help they needed, continued with the task and worked effectively on the unique learning process. Despite all the difficulties, the level of involvement in using AR during the lessons was still high.

   b. Currently, teachers cannot make changes to the AR system to meet the individual needs of students.. This could be solved through an extra link to information that explains the concept in a different way. Additionally, this omission in the app ensures that self-management and differentiation within the group remain limited. More options for personalized settings in the app might be a solution.

If AR needs to be structurally implemented in education, these pedagogical issues need to be addressed.

6. Conclusion

The girls in this study can better visualize abstract concepts in biology using the visualization techniques in AR than traditional educational methods. Concepts that are often indistinctly illustrated and explained in a textbook were clarified in AR using 3D models. The findings of this study thus provide a positive answer to the research question: Does the use of AR positively influence conceptual development about the understanding of the digestive system improve in girls at the lower secondary education level?

Using AR had a positive influence on the concept development of the girls for the chapter nutrition and digestion. Additionally, the students in class 3C could better interpret the concepts of this chapter. This led to an improvement in their learning performance. It should be considered that students worked together on the questions of the worksheet during this research (collaborative learning), while in traditional lessons they often work individually on similar assignments. This means that working together on the assignments has also had a positive influence on correctly answering the questions from the worksheet. The concept of collaborative learning has been widely researched and advocated throughout the professional literature (Ebbens and Ettekoven, 2013). Furthermore, using the app increased students' higher-order thinking skills, and improved the learning process. The students are better able to remember and store information from the chapter nutrition and digestion and apply the information in a new context. They also provided a more critical analysis of the information.

Previous studies about AR in the education showed a positive effect (Lee, 2013). However, there is still room for further development of the AR applications, as well as for the further improvement of this app. The expectation about using AR in the classroom is that more research into AR will follow in the near future, as this technology has enormous potential implications and benefits, especially in education.

And last but not least. Researchers indicate that there are still technological, pedagogical and other challenges in the learning process that need to be bridged if AR is to become a successful tool for education. In addition, the crowded curriculum and the currently limited teaching material can form an obstacle for educational institutions to use AR. To overcome this obstacle and implement AR structurally in biology education requires more qualitative and quantitative studies on the effects of AR on the learning performance and the higher- order thinking skills in secondary education.

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Appendix 1A. Pre-survey

Chemische vertering van voedingsstoffen

Email address *
1. Wat is een ander woord voor enzym?
Mark only one oval.

- Chemische substantie
- Biokatalysator
- Brandstof
- Reservestof

2. Wat is de functie van een enzym?
Mark only one oval.

- De aanmaak van reservestoffen
- Het produceren van hemoglobine
- Het versnellen van chemische reacties
- Het emulgeren van vetten

3. Welke factoren beïnvloeden de werking van een enzym?
Mark only one oval.

- De temperatuur, zuurgraad, enzymconcentratie en substraatspecificiteit
- De enzymconcentratie, koolhydraten, vetten en temperatuur
- De organen, weefsels, eiwitten, en gal
- De locatie van het enzym, en het aantal cellen waar het enzym op inwerkt

4. Wordt een enzym geproduceerd door het lichaam zelf?
Mark only one oval.

- Nee
- Ja
- Gedeeltelijk

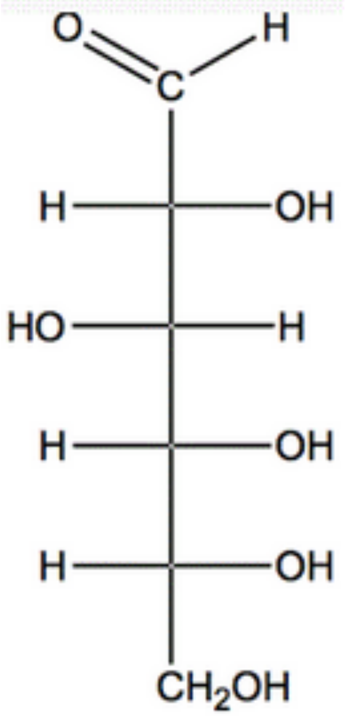
5. Wat is kenmerkend voor een enzym?
Mark only one oval.

- Het eindigt op -ose
- Het werkt reactie-specifiek
- Het heeft een beperkt levensduur
- Wordt zelf verbruikt

6. Bij welke van de onderstaande stoffen hoort de chemische structuur uit afbeelding 1?
Mark only one oval.

- ○ Vetten
- ○ Zetmeel
- ○ Glucose
- ○ Eiwitten

Afbeelding 1.



7. Wat is de functie van het enzym amylase?
Mark only one oval.

- ○ Het verteren van eiwitten
- ○ Zetmeel afbreken tot glucose
- ○ Het produceren van aminozuren(eiwitten)
- ○ Het produceren van zetmeel

8. Welke stof wordt afgebroken door het enzym protease?
Mark only one oval.

- ○ Vetten
- ○ Zetmeel
- ○ Glucose
- ○ Proteïne

9. Waar wordt het enzym protease geproduceerd?
Mark only one oval.

- ○ In de maag
- ○ In de dunne darm

- In de dikke darm
- In de pancreas(alvleesklier) en de darmen

10. Welke enzymen zijn werkzaam in je maag?
Mark only one oval.

- Gastrine en Lipase
- Protease en Lipase
- Amylase en Protease
- Lactase en Lipase

11. Welke enzymen breken amylose (zetmeel) af?
Mark only one oval.

- Protease en Lipase
- Ptyalin en Amylase
- Lysozyme en Gastrine
- Lipase en Gastrine

12. Wat zijn polysacharides?
Mark only one oval.

- Keten van suikers
- Keten van aminozuren
- Keten van nucleotiden
- Keten van diverse soorten moleculen

13. Wat is de functie van amylase?
Mark only one oval.

- Geen idee
- Een zetmeelsplitsend enzym
- Een vetafbrekend enzym
- Een eiwit producerend enzym

14. Waar wordt alfa-amylase geïnactiveerd?
Mark only one oval.

- In de dunne darm, door een basische pH
- In de maag, door de lage pH
- In de alvleesklier, door een hoge pH
- In de lever, door een groot oppervlak

15. Wat is de functie van β-amylase
Mark only one oval.

- Het verteren van vetten
- Het afsplitsen van maltosemoleculen van zetmeel
- Het produceren van aminozuren
- Het afbreken van eiwitten

16. In welk van de onderstaande organismen vind je cellulose?
Mark only one oval.

- In dieren
- In planten
- In bacteriën
- In schimmels

17. Kan cellulose bij mensen worden verteerd?
Mark only one oval.

- Ja
- Nee
- Weet ik niet

18. Welke organen produceren enzymen die nodig zijn voor de spijsvertering?
Check all that apply.

- Lever, dikke darm en endeldarm
- Maag, lever en darm
- Mond, maag, pancreas en darm
- Mond, lever en dunne darm

19. Wat zijn de functie(s) van je speekselklieren?
Mark only one oval.

- Het produceren van speeksel
- Voedsel fijnmalen
- Bacteriën in het voedsel doden
- Voedsel verteren

20. Wat is de functie van speeksel?
21. Wat betekent chemische vertering?

Appendix 1B. Post-survey

Email address *
1. Wat is een ander woord voor enzym?
Mark only one oval.

- Chemische substantie
- Biokatalysator
- Brandstof
- Reservestof

2. Wat is GEEN functie van een enzym?
Mark only one oval.

- De aanmaak van reservestoffen
- Het produceren van hemoglobine
- Het versnellen van chemische reacties
- Het emulgeren van vetten

3. Welke factoren beïnvloeden NIET de werking van een enzym?
Mark only one oval.

- De temperatuur, zuurgraad, enzymconcentratie en substraatspecificiteit
- De enzymconcentratie, koolhydraten, vetten en temperatuur
- De organen, weefsels, eiwitten, en gal
- De locatie van het enzym, en het aantal cellen waar het enzym op inwerkt

4. Wordt een enzym geproduceerd door het lichaam zelf?
Mark only one oval.

- Nee
- Ja
- Gedeeltelijk

5. Wat is NIET kenmerkend voor een enzym?
Mark only one oval.

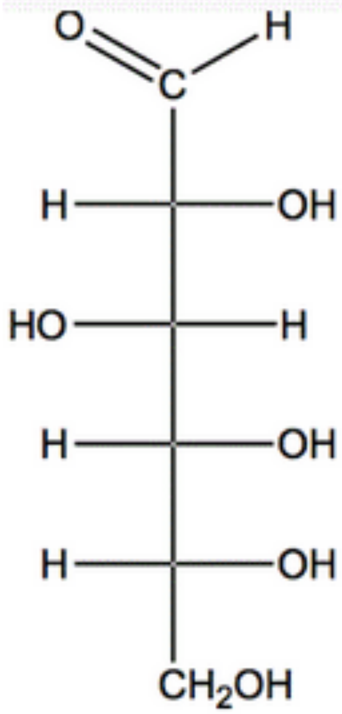
- Het eindigt op -ose
- Het werkt reactie-specifiek
- Het heeft een lange levensduur
- Wordt zelf verbruikt

6. Bij welke van de onderstaande stoffen hoort de chemische structuur uit afbeelding 1?
Mark only one oval.

- Vetten

- Zetmeel
- Glucose
- Eiwitten

Afbeelding 1.



7. Wat is NIET de functie van het enzym amylase?
Mark only one oval.

- Het verteren van eiwitten
- Zetmeel afbreken tot glucose
- Het produceren van aminozuren(eiwitten)
- Het produceren van zetmeel

8. Welke stof wordt afgebroken door het enzym protease?
Mark only one oval.

- Vetten
- Zetmeel
- Glucose
- Proteïne

9. Waar wordt het enzym protease geproduceerd?
Mark only one oval.

- In de maag
- In de dunne darm
- In de dikke darm
- In de pancreas(alvleesklier) en de darmen

10. Welke enzymen zijn NIET werkzaam in je maag?

Mark only one or more oval.

- Gastrine en Lipase
- Protease en Lipase
- Amylase en Protease
- Lactase en Lipase

11. Welke enzymen breken amylose (zetmeel) af?
Mark only one oval.

- Protease en Lipase
- Ptyalin en Amylase
- Lysozyme en Gastrine
- Lipase en Gastrine

12. Waaruit bestaan polysacharides?
Mark only one oval.

- Keten van suikers
- Keten van aminozuren
- Keten van nucleotiden
- Keten van diverse soorten moleculen

13. Wat is NIET de functie van amylase?
Mark only one or more oval.

- Geen idee
- Een zetmeelsplitsend enzym
- Een vetafbrekend enzym
- Een eiwit producerend enzym

14. Waar wordt alfa-amylase geïnactiveerd?
Mark only one oval.

- In de dunne darm, door een basische pH
- In de maag, door de lage pH
- In de alvleesklier, door een hoge pH
- In de lever, door een groot oppervlak

15. Wat is de functie van β-amylase
Mark only one oval.

- Het verteren van vetten
- Het afsplitsen van maltosemoleculen van zetmeel
- Het produceren van aminozuren
- Het afbreken van eiwitten

16. In welk van de onderstaande organismen vind je GEEN cellulose?
Mark only one or more oval.

- In dieren
- In planten
- In bacteriën
- In schimmels

17. Kan cellulose bij mensen worden verteerd?
Mark only one oval.

- Ja
- Nee
- Weet ik niet

18. Welke organen produceren enzymen die nodig zijn voor de spijsvertering?
Check all that apply.

- Lever, dikke darm en endeldarm
- Maag, lever en darm
- Mond, maag, pancreas en darm
- Mond, lever en dunne darm

19. Wat zijn de functie(s) van je speekselklieren?
Mark only one oval.

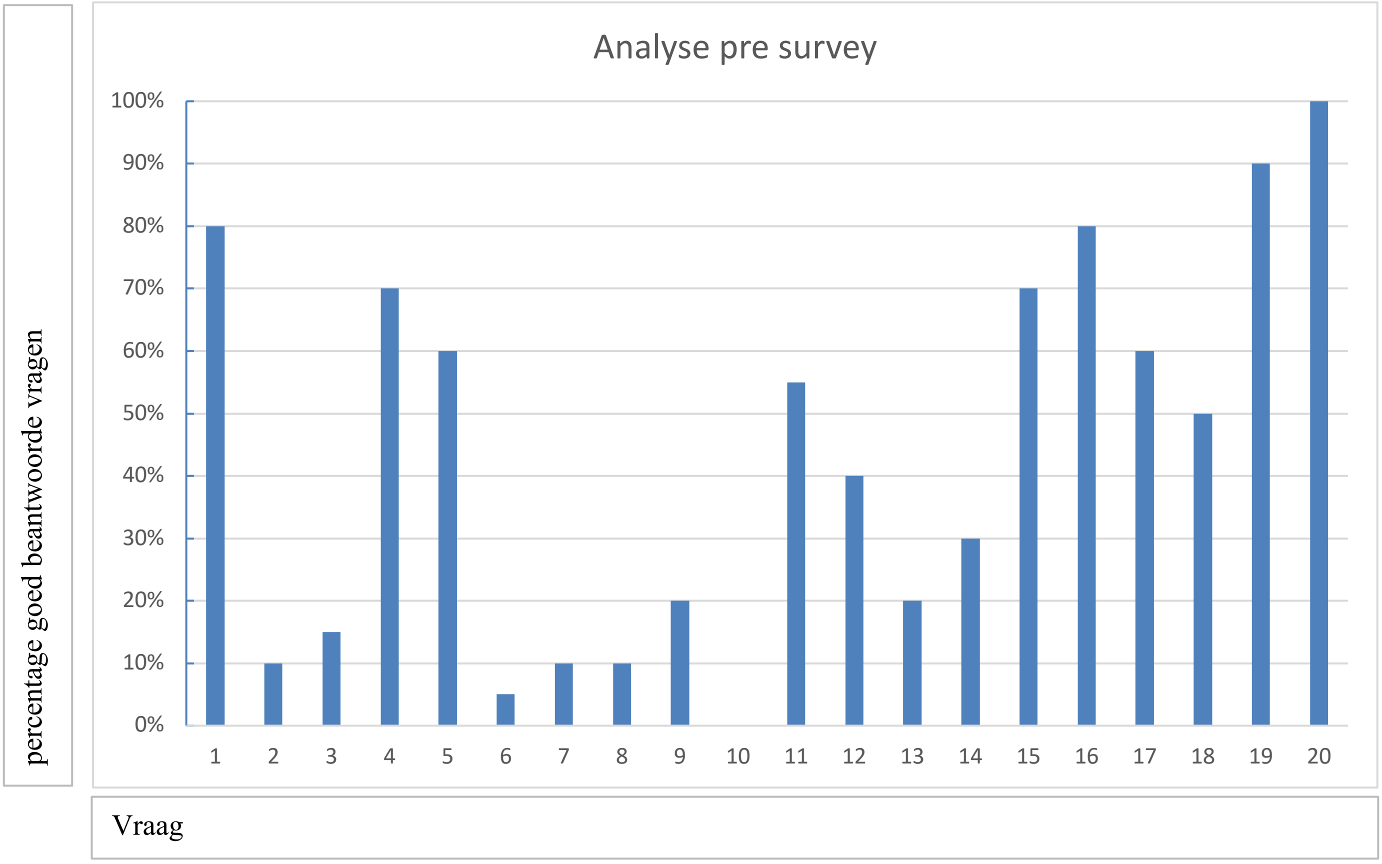
- Het produceren van speeksel
- Voedsel fijnmalen
- Bacteriën in het voedsel doden
- Voedsel verteren

20. Wat zijn de functies van speeksel benoem er 2?
21. Omschrijf het proces van chemische vertering. Verwerk hierin het begrip: chemische vertering. Beschrijf een kort verhaal wat er gebeurt bij de vertering van (kies uit een voorbeeld: koolhydraten, vetten,eiwitten,). En beschrijf een verhaal van mond tot kont in maximaal 150 woorden in de onderstaande tekst vak.

22. Omschrijf hieronder je ervaring met het gebruik van AR tijdens de lessen.

Utrecht University

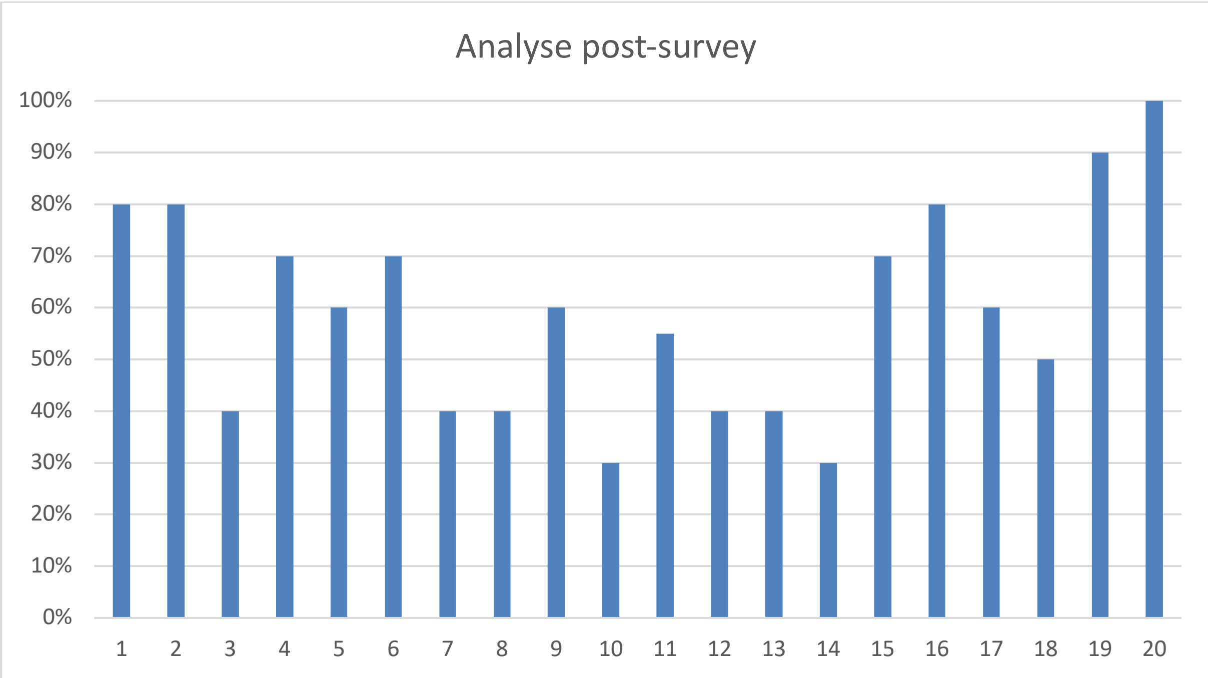
Appendix 2A. Results from the pre-survey



Toelichting: Uit deze gegevens blijkt dat de vragen 6,7,8 en 9 foutief zijn beantwoord. Dit betekent dat de leerlingen moeite hebben met de begrippen: "proteins," starch, and "nutrients."

Appendix 2B. Results from the post-survey

percentage goed beantwoorde vragen



Vraag

Toelichting: Uit deze gegevens blijkt dat de vragen 6,7,8 en 9 beter zijn beantwoord dan de pre-test. Leerlingen hebben de begrippen: "proteins," starch, and "nutrients". Beter beantwoordt. Vraag 6 is voor 65% beter beantwoord. Vraag 7 is 30 % beter beantwoord, vraag 8 is ook 30% beter beantwoordt en ten slotte vraag 9 is voor 40% beter beantwoordt.
Dit betekent dat AR een positieve invloed heeft gehad op de begripsontwikkeling.

Appendix 3A. Worksheets

Chemische vertering van voedingsmiddelen

De onderstaande 10 vragen dien je in tweetallen te beantwoorden m.b.v. de theorie en de app HDS.

Doel:

Het visualiseren van de chemische vertering van voedingsmiddelen

Je begint met het eten van een stukje vlees in de app.

1.Noem alle organen van het verteringsstelsel waar het stukje vlees doorheen gaat

2. Beschrijf wat de verschillende verteringssappen met het stukje vlees doen

3. Wat is de functie van amylase?

4. Welke stof(fen) komen er in het stukje vlees voor?

5. Welke stof(fen) komen er in banaan voor?

6. Hoe noemen we de beweging van de slokdarm naar de maag?

7. Hoe heet het enzym dat eiwitten splitst?

8. Wat is de functie van het enzym lipase?

9. In welk orgaan wordt de pH van zoutzuur geneutraliseerd?

10. Invulopdracht verteringsstelsel (gebruik hierbij de APP en zo nodig je BINAS)

Vul in:

- uit welke koolhydraten (zetmeel) het voedingsmiddel bestaat
- en waar deze koolhydraten worden afgebroken, zet een streepje als deze voedingsstof in het betreffende onderdeel van de spijsvertering niet afgebroken wordt of aanwezig is
- geef ook aan welk enzym hierbij betrokken is
- **Invulopdracht verteringsstelsel (gebruik hierbij de APP en zo nodig je BOEK)**

Vul in:

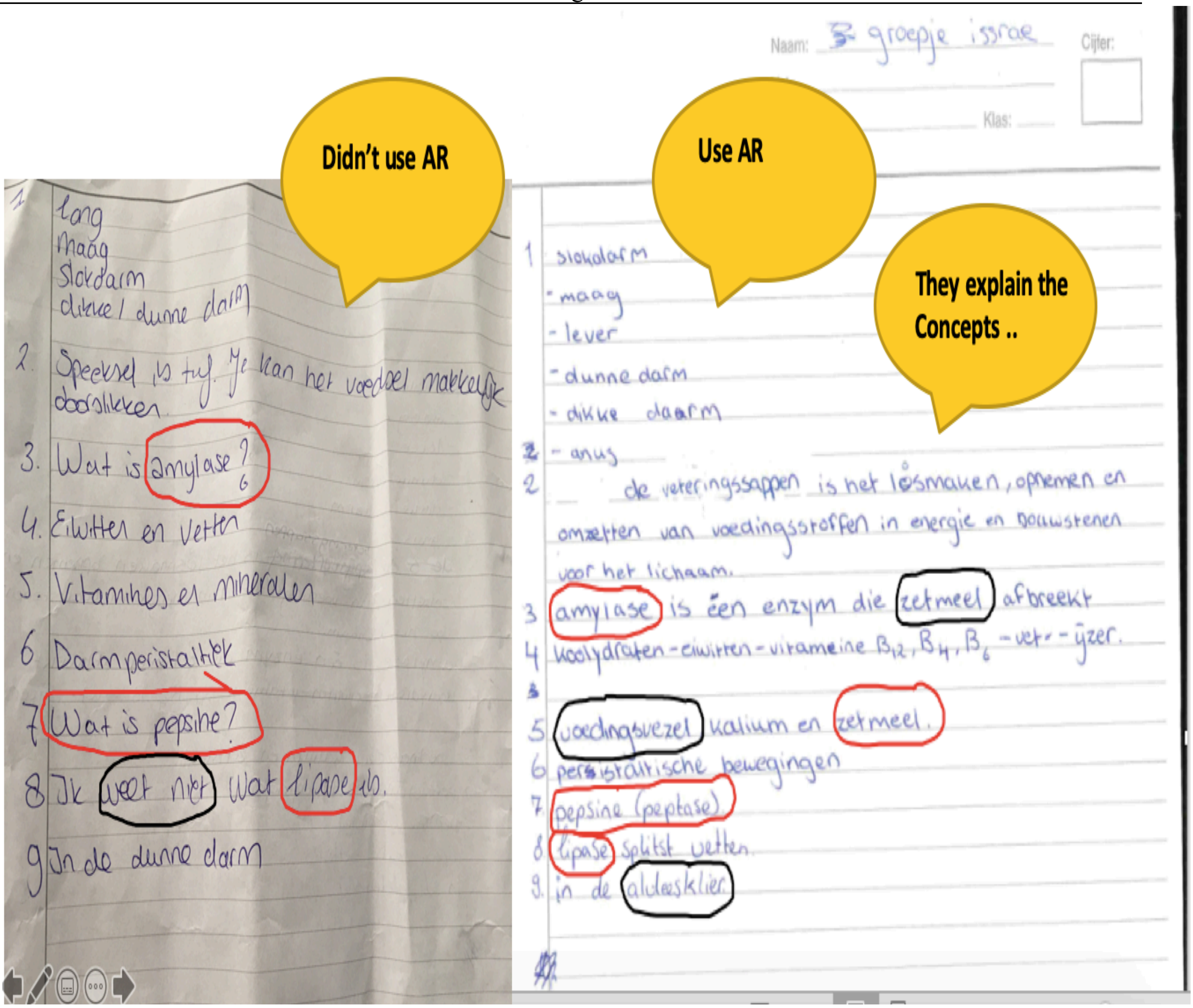
- uit welke koolhydraten (zetmeel) het voedingsmiddel bestaat
- en waar deze koolhydraten worden afgebroken, zet een streepje als deze voedingsstof in het betreffende onderdeel van de spijsvertering niet afgebroken wordt of aanwezig is
- geef ook aan welk enzym hierbij betrokken is

Voedingsmiddel Verteringsstelsel	Banaan		Brood		Water		Vlees	
	Koolhydraten	Enzym	Koolhydraten	Enzym	Koolhydraten	Enzym	Koolhydraten	Enzym
Mond								
Maag								
Dunne darm								
Dikke darm								

Utrecht University

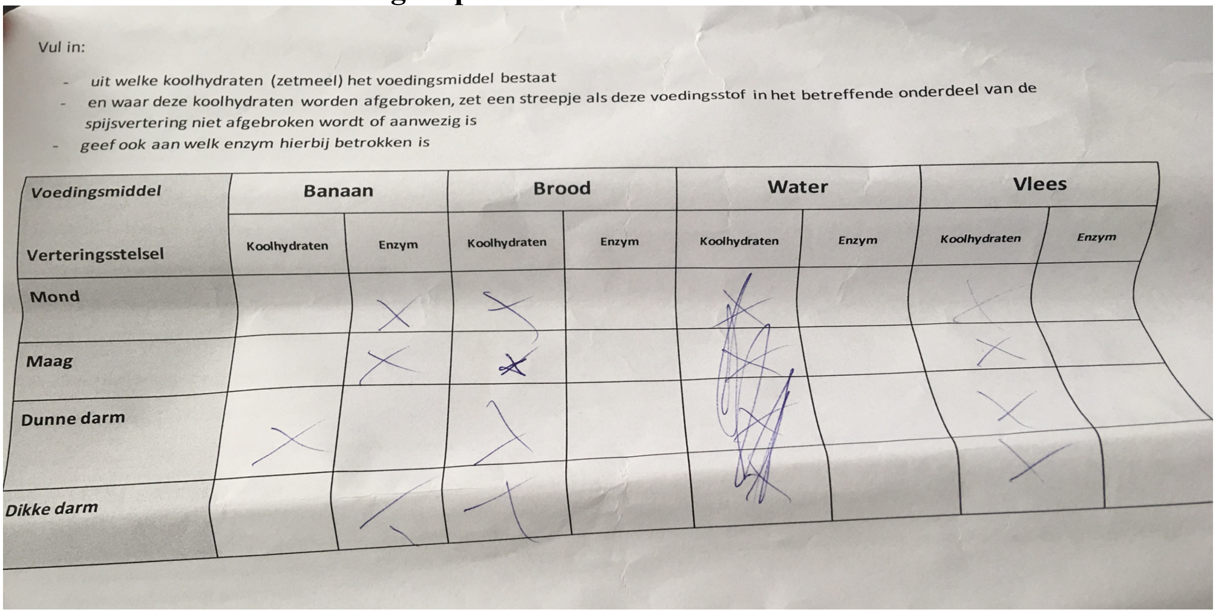
Appendix 3B. Answers on worksheets part 1

Difference in responses between the group that used the AR or not.
Left side: answers form class 3B and on the right side answers from class 3C.



Appendix 3C. Answers on worksheets part 2

Class 3C. Answers from the group that did use AR

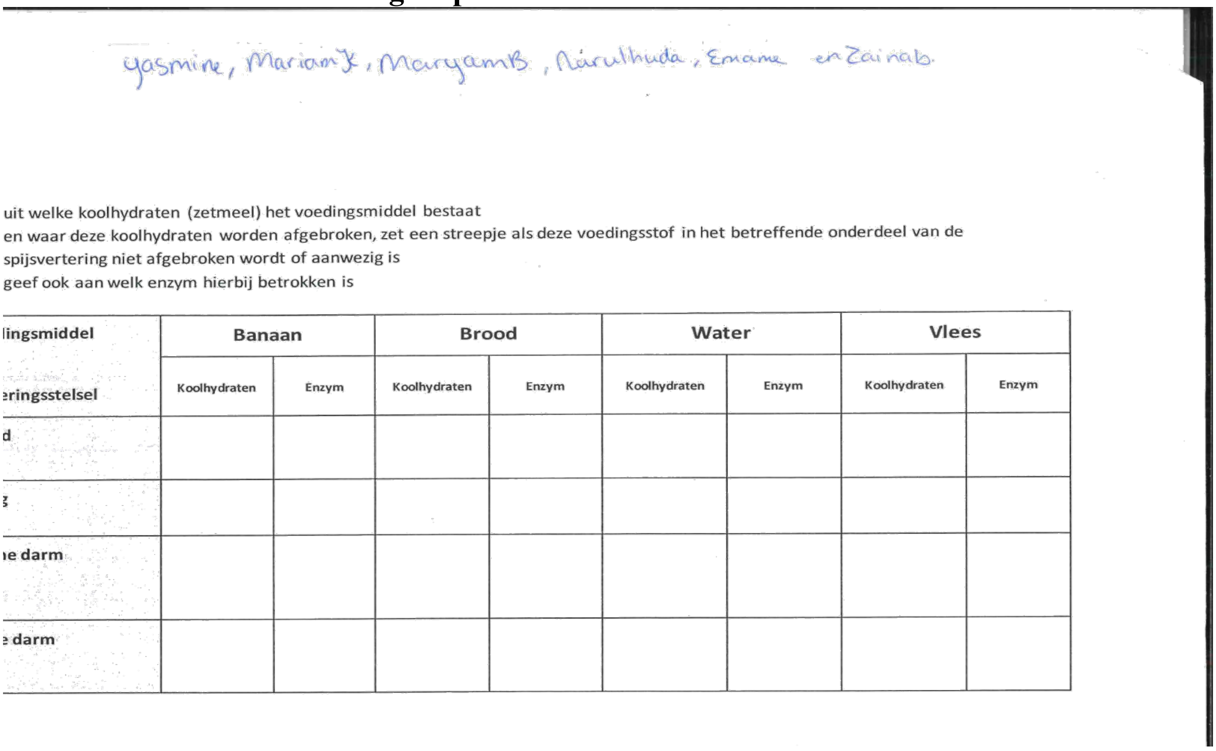


Vul in:

- uit welke koolhydraten (zetmeel) het voedingsmiddel bestaat
- en waar deze koolhydraten worden afgebroken, zet een streepje als deze voedingsstof in het betreffende onderdeel van de spijsvertering niet afgebroken wordt of aanwezig is
- geef ook aan welk enzym hierbij betrokken is

Voedingsmiddel	Banaan		Brood		Water		Vlees	
Verteringsstelsel	Koolhydraten	Enzym	Koolhydraten	Enzym	Koolhydraten	Enzym	Koolhydraten	Enzym
Mond		X	X				X	
Maag		X	X				X	
Dunne darm	X		X				X	
Dikke darm		X	X				X	

Class 3B. Answers from the group that didn't use AR



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uit welke koolhydraten (zetmeel) het voedingsmiddel bestaat
en waar deze koolhydraten worden afgebroken, zet een streepje als deze voedingsstof in het betreffende onderdeel van de spijsvertering niet afgebroken wordt of aanwezig is
geef ook aan welk enzym hierbij betrokken is

lingsmiddel	Banaan		Brood		Water		Vlees	
eringsstelsel	Koolhydraten	Enzym	Koolhydraten	Enzym	Koolhydraten	Enzym	Koolhydraten	Enzym
d								
g								
ne darm								
e darm								

Appendix 4. Observatieformulier

OBSERVATIEFORMULIER AR in de klas			
Datum & lesuur:	School: Cornelius Haga Lyceum	Docent: Teslime Temur	Vak: Biologie
	Deze observatieformulier is gebruikt gedurende dit onderzoek. Waarmee aan de hand van de video opnames waarin augmented reality in klas 3C is gebruikt de onderstaande punten zijn geanalyseerd met de vraag: ‘In welke mate onderneem ik de volgende activiteiten?’		

Schaal (en indicator)	**1 (N/A)**	**2 (nauwelijks)**	**3 (een beetje)**	**4 (sterk)**	**Toelichting** (geef hier voorbeelden van wat je gezien hebt)
Leerdoelen/context					
Vaststellen duidelijke leerdoelen (kennis, begrip, vaardigheden)	○	○	○	●	Leerdoelen werden van tevoren uitgeschreven op het bord, en waren voor de leerlingen duidelijk zichtbaar.
Voorkennis activeren/relatie met voorgaande les	○	○	○	●	Voorkennis is geactiveerd met behulp van een mindmap.
Rubric/handvatten voor leerlingen om leerdoel(en) te monitoren	○	○	○	●	In het tekstboek staan de leerdoelen tevens vermeld.
Reflectie op leerdoelen: behaald en relevant?	○	○	○	●	Aan het einde van de les zijn de leerdoelen getest met behulp van open vragen.
Focus op individueel leren					
Gebruik *pre-assessment* om individuele leerdoelen vast te stellen	○	○	●	○	
Checkt/monitort tussentijds of leerlingen het begrijpen	○	○	○	●	Vooral tijdens het werken m.b.v. AR zijn is de kennis van leerlingen gemonitord.
Instructie 1: duidelijk en activerend					
Communiceert duidelijke uitleg voor uitvoeren leertaken/opdrachten	○	○	○	●	Het programma werd duidelijk toegelicht en stond tevens op het bord.
Stimuleert actieve deelname van alle leerlingen	○	○	○	●	
Instructie 2: differentiërend					
Adaptieve instructie voor verschillende leerlingen	○	○	○	●	
Creëert verschillende leeractiviteiten voor verschillende leerlingen	○	○	○	●	Leerlingen konden gebruik maken van de informatie uit het tekstboek en hun mobiele telefoon om de vragen op het werkblad te beantwoorden met behulp van de app HDS.
Feedback					

Helpt leerling bewust te worden van eigen talenten en eigen leerstrategie	○	○	○	●	Leerlingen werden aangesproken op hun eigen verantwoordelijkheid en het zelfstandig vergaren van kennis.
(Geeft) Positieve feedback + waardeert aanpak/strategie	○	○	○	●	
(Geeft) Corrigerende feedback + bespreekt aanpak/strategie	○	○	○	●	Tussendoor kregen de leerlingen vaak feedback van de docent. Leerlingen gaven elkaar ook onderling feedback.
Keuzevrijheid/autonomie-ondersteuning					
Open voor leerling perspectief, begripvol naar leerlingen	○	○	○	●	
Houdt in les rekening met interesses van leerlingen	○	○	●	○	
Creëert mogelijkheden voor leerling om op eigen manier te werken, biedt keuzes in HOE	○	○	○	●	Autonomie van de leerlingen tijdens de samenwerkingsopdracht is gestimuleerd.
Creëert mogelijkheden voor leerling om eigen lesinhoud te kiezen, biedt keuzes in WAT	○	○	○	●	
Inzet van ICT					
Soepele transities tussen wel/niet ICT-gebruik	○	○	○	●	
Leeractiviteit met ICT is duidelijk, gebruiksvriendelijk voor leraar & leerlingen	○	○	○	●	Docent heeft de app HDS toegelicht.
ICT faciliteert gepersonaliseerd leren van leerlingen	○	○	○	●	Leerlingen konden zelf stoeien met de stof met behulp van de app HDS.
Leerlinggedrag					
De leerlingen zijn betrokken bij de les	○	○	○	●	Dat de leerlingen gedurende de lessen meer geactiveerd en betrokken waren met behulp van AR was duidelijk zichtbaar.
De leerlingen tonen zich geïnteresseerd	○	○	○	●	De leerlingen stelden meer vragen onderling bij het

					beantwoorden van de vragen. Tevens ook naar de docent toe.
De leerlingen zijn actief op leren gericht	○	○	○	●	
De leerlingen zijn meer gemotiveerd	○	○	○	●	Bij het werken aan de vragen uit het werkblad waren de leerlingen eer gemotiveerd dan de lessen waarin ze geen AR gebruiken.

Appendix 5. Interview

Interviewvragen over het gebruik van AR in de klas. **31-10-2019** **Klas: 3C** **Cornelius Haga Lyceum**

1. Wat vind je van de toepassing van AR in biologie?
Z. Leuk, interactief en het is duidelijker. Je ziet namelijk hoe alles wordt verteerd in het lichaam. Daardoor begrijp ik de begrippen nu veel beter.
I. Leuk en interessant. Ook leerzaam. Normaal gesproken leren we dit ook in de theorie, en nu zien we hoe deze vertering plaatsvindt.
M. Ik vond het heel interessant, normaal weet ik niet hoe die modellen en plaatjes eruit zien. Ik zie dit niet helemaal voor me. En nu zag ik dat opeens. Ook al had ik eerder informatie gelezen over een begrip bijvoorbeeld merkte ik dat het hierdoor veel duidelijker werd.

2. Welke voordelen heeft de toepassing van AR in biologie volgens jou?
Z. Leerlingen krijgen meer inzicht in hoe alles werkt, in het boek staat het globaal beschreven en met dit app krijg je meer diepgang.
I. Bepaalde dingen worden duidelijker, in je boek staat het vaag. Ik heb een beter beeld bij als we AR toepassen bij de stof.
M. Dat het zichtbaar werd is echt interessant, ik denk dat de toetsen beter gemaakt zullen worden en dat het de leerlingen zal motiveren om te oefenen met de stof.

3. Wat motiveert jou voor deze activiteit?
Z. Samen te werken, de opdrachten waren wat makkelijker. Het was erg realistische en we zagen hoe die vertering als proces plaatsvond.
I. Ik vond het een hele leuke opdracht, in de 1e en 2e klas hebben we het gehad over vertering maar had tot nu toe niet zo een diep beeld bij. En dat beeld motiveerde mij voor de opdracht.
M. De opdracht(werkblad) was motiverend
voor mij. En het zien van de bewegende beelden m.b.v. de app motiveerde mij om te werken aan de opdrachten. **Het zorgde voor een groter begripsvorming.**

4. Word je door AR uitgedaagd om je best te doen?
Z: Ja, je zag het duidelijker. Vragen waren prima te doen.
I: Eigenlijk wel, ik kreeg er meer zin in. Je wordt leergierig. **Ik zag letterlijk hoe die vertering werkte en dat motiveerde mij.**
M: Zeker, ik vind dat AR zijn werk goed doet. **Het helpt echt om dingen te verduidelijken.**

5. Hoe tevreden ben je over het gebruik van AR tijdens de les?
Z: Heel leuk.
I: Heel leuk erg tevreden.
Maryam: Ja, was echt gepast voor deze stof.

6. Vind je dat je echt iets leert m.b.v. AR?
Z: Jazeker, je ziet alle organen van het verteringsstelsel en hoe alles werkt.

I: Ja, veel meer dan wanneer je alleen een boek gebruikt tijdens de les. En als je AR gebruikt zie je ook echt hoe dingen werken en begrijp je de stof beter.
M: Ja, beter dan alleen boeken gebruiken. Mensen worden suf van alleen de stof. Het is fijn om ook verandering te hebben.

7.Merk je dat je digitaal vaardiger bent geworden m.b.v. AR?
Z: Nee, niet echt.
I: Nee niet echt.
M: ook niet echt.

9. Met AR kun je biologie levensecht, interactief maken. Denk jij dat AR dit mogelijk maakt in biologie?
Alle drie hebben dit gevoel wel ja.

10. AR kan een karakter uit het verhaal projecteren in de huidige omgeving. Denk jij dat leerlingen hierdoor een intensere les zullen beleven?
Het is wat realistischer, en laat zien hoe alles werkt.

11. AR kan 3D-toevoegingen bieden. Denk jij dat een 3D-ervaring leerlingen meer zal uitdagen tijdens de les?
Z: verschilt per leerling. Sommige vinden biologie niet leuk. Voor mij wel.
I: Jazeker
M: Ja, want het biedt meer veranderingen, en leerlingen vinden dit interactiever.

12. Denk jij dat het gebruik van AR leerlingen kan stimuleren om meer zelfstandig te leren?
Z: Jawel, het is duidelijker en je kunt makkelijker vragen beantwoorden.
I: Ja, ik denk door het gebruik dat leerlingen meer zin in krijgen en dat het hen stimuleert om meer te leren. **Het helpt ook zeker met het huiswerk, je zou dit dan erbij kunnen pakken.**
M: Ligt aan de situatie, in de vakantie gaan de leerlingen minder leren. Maar als je bijvoorbeeld deze app zou gebruiken zou ik dit ook wel thuis willen gebruiken.

13. Heeft AR je gestimuleerd tot een beter begripsvorming bij het hoofdstuk voeding en vertering?
Z: Jawel, de termen van het hoofdstuk voeding en vertering werden duidelijker. Als ik de app niet had gebruiken zou ik deze termen niet kennen.
I: Denk het wel, als je geen beeld hebt hoe die vertering werkt is het lastig te volgen maar door deze app werd het duidelijker.
M: Ja, wegens het zien van die begrippen. Ik denk dat als je lesgeeft ook actiever bezig kan zijn. En dit waarderen we als docenten dit inzetten, docent vraagt meer om de wensen van de leerling.

14. Wat zijn volgens jou de nadelen van AR?
Z: Soms vond ik het een beetje moeilijk omdat ik niet wist hoe ik de app moest gebruiken, toen ik ermee ging oefenen werd het duidelijk.
I: De app is niet duidelijk. Als de app meer wordt ontwikkeld met een gebruikershandleiding, link met uitleg bijvoorbeeld op de voorpagina.
M: Ik vond de app niet overzichtelijk, als je op dingen ging klikken was het lastig om bij het juiste onderdeel te zijn.

15. Welke rol kan augmented reality spelen bij het ontwikkelen van een breder begripsvorming in de klas?

Z: Meer informatie over de begrippen.
I: Ja denk het wel, de app was nog een beetje beperkt.
M: Ja denk het wel. Het zou makkelijker zijn als er in de app wat toevoegingen worden gedaan, over bijvoorbeeld de definitie van de begrippen.

16. Voor welke hoofdstukken van biologie zou AR verder nog meer geschikt zijn volgens jou?
Z: Vertering, voortplanting, bijna alle hoofdstukken kan het in principe gebruikt worden.
I: Ik denk dat het voor de hoofdstukken: voortplanting, en voeding en vertering geschikt zou zijn. Ook bij genetica.
M: Bloedsomloop.

17. Welke toepassingen zouden nog meer toegevoegd kunnen worden voor deze app?
Z: Begripsvorming, test jezelf. Of als je een toets hebt overhoorprogramma instellen.
I: App zou breder ontwikkelt kunnen worden, voor iedere hoofdstuk iets in de app toevoegen.
M: Bij alle hoofdstukken informatie toevoegen.

18. Versterkt AR de visualisatie van termen?
Jazeker, vooral bij voeding en vertering is het belangrijk dat je er een beeld bij hebt. Door dit app heb ik dit wel.

19. Kan je beter scoren op de toetsen mbv AR?
Jazeker.