Fostering primary school children's understanding of proteins through an educational AR app

Anne Heemskerk

Thesis

18.05.2022

Utrecht University

Supervisor: Dr. H.E.K. (Henri) Matimba

Second examiner: E.P.H.M (Liesbeth) de Bakker Msc

Abstract

Science is often known to the general public as being difficult and scary. Since science anxiety already starts at primary school, it is argued that it is best to start teaching science at that age. A way to do so is by presenting science in an interactive and entertaining way. Even though science education is seen as important in primary schools it is not realised due to the overcrowded curriculum. This research project proposes to contribute to children's understanding of proteins by investigating an augmented reality assisted app that learners can use to gain knowledge about and insight into this topic. While investigating this, it is also examined whether this app tackles the problem of misconceptions that the learners may have about proteins.

The main research question *To what extent does an augmented reality assisted protein app support primary school children (aged 9-12) in their understanding and engagement regarding proteins?* is answered in a qualitative research through 6 sub-questions by means of surveys, interviews, and observations. 16 participants from two different primary schools completed a pre questionnaire, after which they played the hemoglobin challenge of the BodyBits app, and then completed a post questionnaire. After a period of 8 weeks 7 of the participants were interviewed.

It can be concluded that however the target group's prior knowledge regarding proteins is limited and they may need more guidance than the app now gives them, the participants are able to deal with abstract and complex information on a sufficient level. On the formative assessment questions of the questionnaire, the participants scored reasonably high, considering they have not been taught about proteins before. However, most participants did not retain this knowledge after a period of 8 weeks. Nonetheless, the game seemed to be engaging to the target audience, which was expressed in the questionnaires and interviews but was also observed when they were playing the game.

Table of contents

1. Introduction

Science influences our everyday life in many ways. It has, for instance, enabled us to develop and have access to computers, cell phones, the internet, and an advanced health care system. Science can also help us to understand the world around us and makes life better and easier. Living in a world that is technology-based, it is beneficial for citizens to achieve a base level of understanding of science in order to make full use of its potential.

However, science is often known to the general public as being difficult and scary. In 1978, Mallow introduced the term "science anxiety" (Mallow, 1978). This anxiety lowers confidence, causes pupils to expect themselves to perform poorly, to have less interest in science, and to avoid science subjects and eventually science careers. Since science anxiety already starts at an early age (Chiarelott, L., and Czerniak, 1987), it is argued that it is best to start teaching science at an earlier age (i.e., at primary school). A way to do that is by presenting science in an interactive, user-oriented, and entertaining way, and so take away the association with fear and difficulty, making place for interest, enjoyment and even passion.

One of the main purposes of science education is to foster the scientific literacy of learners. The definition of scientific literacy that is referred to here is "knowledge needed for intelligent participation in science-based social issues" (Norris & Phillips, 2003). A key factor in the learning experience and achievement of students is motivation (Bouffard, T., & Vezeau, 1998; Dweck, 1986; Gottfried, 1990; Wilson & Corpus, 2001)**.** Therefore, self-determination theory is reviewed in the context of gamification in the theoretic background.

Regardless of the motivation of the students, the fields of science and technology are prone to naïve concepts, also known as mis- or preconceptions (Turkmen & Usta, 2007). Misconceptions are inaccurate or incomplete pre-existing ideas that learners hold when they come to the classroom. These misconceptions occur in abundance in the fields of biology and chemistry (Cakir, 2008; Kerr & Walz, 2007; Lazarowitz & Lieb, 2006), but are experienced in all scientific fields.

One of the topics in biology that is often not well-known or misunderstood, is that of proteins (Marbach-Ad, 2001; Wood-Robinson et al., 2000). For example, what proteins are and how they function is not common knowledge. This is especially so for primary school children, the target group of this research. As learning about proteins is not part of the Dutch primary school curriculum, this absence of knowledge is then reflected in ideas about food and nutrition, causing children to misinterpret the importance of good nutrition or a balanced diet. Since misconceptions can be hard to extinguish, it is important to identify and cope with them as soon as possible.

The main goal of this research is to investigate an app that learners can use to gain knowledge about importance and function of proteins, and while doing so examine whether this app tackles possible misconceptions that the learners may have about proteins. It is investigated how to best explain difficult concepts to children that they may not know anything about yet. In this case, by means of simple, intuitive actions and pictures using augmented reality and gamification.

Proteins, as many scientifical concepts, are not visible to the naked eye. Lack of visual representation of such concepts makes them difficult to understand. The use of technology, however, can help to familiarize children with the concept of proteins. Augmented reality in particular is a powerful means to make science visible, tangible and interactable. Furthermore, augmented reality can improve comprehension and increase motivation (Chytas et al., 2020; Wu et al., 2013).

This research project focusses on how augmented reality technology and gamification can help to make invisible proteins visible and interactable. Additionally, a sticker book is used, containing stickers of anthropomorphized proteins. These are depiction of proteins this way is to make the topic more appealing and engaging for the designated age group, being children aged 9-12 (i.e., at the end of primary school in the Netherlands). The stickers are to be collected by kids (like "voetbalplaatjes" from Albert Heijn) and contain a QR code that can be scanned by the developed app. This app shows more information about the protein, like a 3D visualization of the structure and its function. Furthermore, a game about the scanned protein will be unlocked to play. The Body Bits app with accompanying Protein Sticker Book is designed to be a fun and engaging, in such a way that science more accessible and to familiarize children with proteins and their functions at an early age.

In specific, the research aims are to obtain insight into the construction of abstract concepts concerning chemical reactions and structure by using the developed Body Bits app. In this project, the target group's prior knowledge and misconceptions are explored, as well as whether the established learning goals are reached through playing the developed BodyBits app, which is a handheld augmented reality simulation game designed to support learning about proteins in order to familiarize the target audience with them. The project focusses on a specific part of the app that has been developed – the hemoglobin challenge.

The main research question is:

To what extent does an augmented reality assisted protein app support primary school children (aged 9-12) in their understanding and engagement regarding proteins?

Sub-questions that help to answer this question include:

1. *What is the target group's prior knowledge and/or what are their misconceptions regarding proteins?*

To know whether the app aligns with the prior knowledge of the participants, the prior knowledge of the target group is investigated. Also, misconceptions the target group might have been examined, to be able to cope with these in further studies.

2. *To what extent can the target group deal with abstraction and understand what scientific models are?*

Proteins are not visible to the naked eye and therefore abstract. It is important to know to what extent the target group can understand this abstract idea, to know whether the participants are able to fully understand the information that they are meant to gather from playing the hemoglobin challenge. Furthermore, in the app, scientific models are used to portray the function of proteins. It is therefore important to know whether the participants are able to understand what scientific models are.

3. *Are the learning goals reached through playing the developed interactive game?*

Beforehand, 4 cognitive goals and 1 affective goal were established for the hemoglobin challenge. It is important to know whether these learning goals are reached, because otherwise the hemoglobin challenge might need some adjustments.

4. *Is the developed game engaging for the target audience?*

Since this app is meant to be used in informal education, it is important to know whether the game is engaging for the target audience. If the challenge is not engaging, this might be an indication that the target group will not play the games as much, and therefore will not learn about proteins.

2. Relevance of the study

The goal of this research is to make users, in the age of 9-12, gain a basic understanding of proteins and to make them eager to learn more. Augmented reality is a powerful means to make abstract concepts visible and interactable. In this project, AR is used to aid pupils in developing a (realistic) visualization of proteins, and with the added gamification element also hopefully motivate them to learn more about the topic. Although one might argue the target group is too young for the complexity of this subject, we believe that introducing proteins at this young age can provide a steppingstone for the pupils. When they learn about proteins in a later stage of their school career, they hopefully will remember this first encounter with proteins and have less difficulties with the abstract thinking and/or thinking in models that is required to understand how proteins work. Familiarizing the pupils with abstract thinking might also prevent misconceptions that pupils might otherwise form.

Furthermore, the developed app ensures that a teacher who uses the app, can do so with minimal preparation time or knowledge about proteins. As the app explains scientific concepts without a lot of assistance pupils can learn in their own time and rate.

This project started out as an assignment of the European Proteomics Infrastructure Consortium Providing Access (EPIC-XS) to design an AR product to teach children about proteins.

3. Theoretical framework and research

In this chapter, first, in section 3.1 motivation is discussed considering gamification, as this is of great influence on the learning of primary school children. As misconceptions in this field exist, existing literature on this is discussed in section 3.2. In sections 3.3 and 3.4, literature on gamification and augmented reality is reviewed, since the developed BodyBits app makes use of those elements. Furthermore, to support children in making the abstract topic of proteins concrete, visualization and use of language are discussed in section 3.5.

3.1 Motivation as a key factor in students' learning

Motivation is a key factor in students' learning experience and academic performance (Bouffard, T., & Vezeau, 1998; Dweck, 1986; Gottfried, 1990; Wilson & Corpus, 2001). According to the self-determination theory of Deci and Ryan, there are three basic psychological natural needs necessary for motivation to learn and develop: autonomy, competence and relatedness (Ryan & Deci, 2000). When considering gamification, the first need can be met by offering a moderate amount of meaningful challenges that support learning, as the learner is then more likely to feel autonomous (van Roy & Zaman, 2017). The need of competence can be met through gamification by creating activities that provide a significant challenge while nevertheless appearing as achievable, and by providing the learners with positive competence-related feedback (van Roy & Zaman, 2017). Furthermore, the last need can be achieved by facilitating social interaction between users to support their feelings of relatedness (van Roy & Zaman, 2017).

3.2 Misconceptions regarding proteins and prior knowledge

The subject of proteins is not in the curriculum of Dutch primary schools, so it is safe to assume the target group (aged 9-12) generally has not received any schooling on this topic (SLO, 2018). The ideas the target group might have about proteins can therefore be considered as naïve knowledge and are likely to contain misconceptions. Learners gain naïve theories through everyday experiences with the world, rather than through scientific explanations (Gelman & Noles, 2011).

There is a lot of literature on naïve knowledge and misconceptions in the field of biology. For example, Reiss et al. performed a large-scale multinational survey including 54 nations, showing that 7-year-old children already had a basic understanding of their organs (Reiss et al., 2002). In an older study by Reiss et al, children displayed limited understanding of the relationships between organs and organ system, although they did demonstrate a rudimentary understanding of organs like the heart, brain, stomach and skeleton, as well as a relatively accurate sense of size and position inside the body (Reiss & Tunnicliffe, 1999). It was also found that 7-11 year old children portrayed individual organs rather than groups of organs in their drawings of the human body (Reiss et al., 2002). Because pupils have no knowledge of molecular systems at this age, they have no notion what happens within the body or what the organ systems' functions are (Reiss et al., 2002).

As an example of naïve knowledge about proteins, In Dutch, the word for egg white ("eiwit") is the same as that for a protein (also "eiwit"), which causes confusion. Pupils aged 9-12 are likely to associate proteins with egg white. As a result, pupils might be inclined to think that proteins only or mainly exist in egg white or might not even know the meaning of "eiwitten" in the broader context of proteins.

As stated in the introduction, misconceptions are inaccurate or incomplete pre-existing ideas that learners have when they enter the classroom. These occur when there is a mismatch between the scientific concept and the pupil's mental functioning level, cognitive achievement or IQ status of the learners (Turkmen & Usta, 2007). Misconceptions can also occur through informal learning. Correction of a misconception requires the learner to be aware of the misconception as well as to be unsatisfied with it, because there is better plausible new information to replace the misconception with. Technological tools, like augmented reality, can help eliminate misconceptions (Turkmen & Usta, 2007).

In this research, the visualization of the protein and its function is used to aid the participants to build a correct internal visualization of how the protein works in the human body and hereby attempts to prevent the origination of misconceptions or to replace existing misconceptions with correct concepts.

3.3 Gamification

Gamification is the implementation of game elements in science education (Kalogiannakis et al., 2021). Although the interest for and research in this field is extensive, creating this in a competitive environment is controversial. In science education, gamification is used to prohibit pupils' negative attitudes and experiences with science and to improve learning outcomes. The research outcomes in this field are variable, although mostly positive. In their literature review on gamification in 2021, Kalogioanakis et al. point out several issues with the current research on gamification. For example, they indicate that gamification studies often lack a formal design process. Furthermore, it is often unknown which game element causes which effect. Therefore, it is not possible to determine causal relationships between game elements and effects. Moreover, the quantity and quality of gamification research in general is too low (Kalogiannakis et al., 2021). This research was built upon what is known about gamification and aims to develop further knowledge on this subject. In particular, this research used augmented reality and gamification in an attempt to aid pupils' understanding about proteins.

3.4 Augmented reality

This project is meant as an exploration of the possibilities of creating educational augmented reality content and at the same time to find out what factors determine what good AR content is. In literature, augmented reality has been defined in various ways. In 2008, Klopfer et al. defined a broad definition, whereby augmented reality is seen as any technology that incorporates experiences in the real and virtual world in a meaningful way (Klopfer & Squire, 2008). Wu et al. on the other hand, define it as “a system that fulfils three basic features: a combination of real and virtual worlds, real-time interaction, and accurate 3D registration of virtual and real objects” (Wu et al., 2013). Augmented reality can be implemented by varied devices, such as desktop computers, head-mounted displays, and other mobile devices. In this project, we used mobile devices. By doing this, we make our product accessible to the target audience, without having to use specialized equipment.

According to Wu et al. augmented reality may enhance understanding of dynamic models, facilitate the development of investigation skills, improve spatial skills and provide the opportunity to manipulate virtual objects or visualize models and concepts that are invisible to the naked eye (Wu et al., 2013). In a study by Chytas et al. augmented reality is implemented in anatomical education (Chytas et al., 2020). Here, the use of augmented reality proved to be able to increase motivation, engagement and foster a deeper understanding of abstract concepts (Chytas et al., 2020). Because the topic of proteins is also in the domain of biology, this is an indication that our designed product might also have similar effects.

3.5 Visualization and use of language

Since proteins are invisible, in this project, approaches were explored to make the topic more engaging and comprehensible for the target audience. In the design of this augmented reality assisted sticker book, it is important that the stickers and visualizations in the application are attractive to the target audience. When trying to grasp new concepts, children use anthropomorphism (Piaget, 1929; Watts & Bentley, 1993). In this research, anthropomorphism is therefore used to make the concepts more relatable and understandable for the target group. Making use of this mechanism, the molecules in the designed app are depicted as spheres with faces. There is however a possible negative effect of oversimplifying the real structure of molecules by anthropomorphizing them. Namely, the target group do not relate the visual representation to molecules because the molecules are depicted as spheres with faces and therefore less recognizable as molecules.

According to Dorion however, anthropomorphism is an effective way to introduce new scientific concepts to our target audience (Dorion, 2011). Therefore, the proteins and food stickers are visualized in an anthropomorphized manner (see Figure 1). Also, the challenges are anthropomorphized as much as possible. For example, in the hemoglobin challenge (explained in detail in section 3.1), the oxygen and carbon dioxide molecules have faces. Depending on the location of the challenge (the lungs or the muscles), the sounds in the app are “happy” or “disappointed” to guide the user.

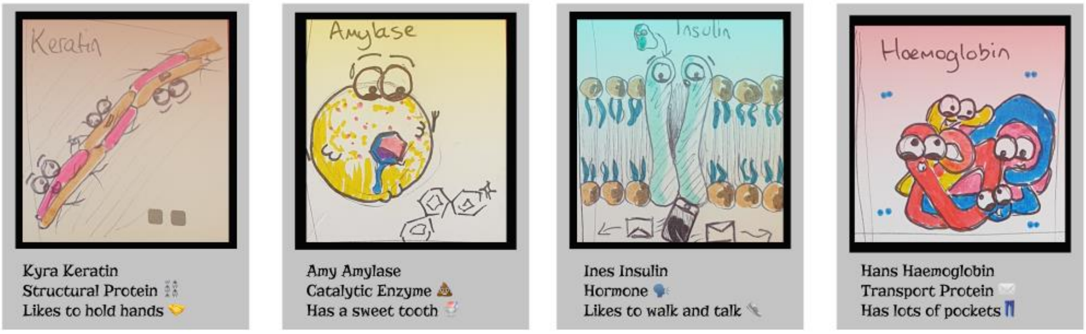

***Figure 1**: Prototypes of the anthropomorphized protein stickers with names that are recognizable for the target audience.*

Of course, the information in the sticker book and the app are based on scientific facts. Because the target audience is young (age 9-12), it is a challenge to convey the scientific concepts in an easy and accessible way. However, by placing them in familiar contexts the concepts appear more relevant to the target group (Gilbert, 2006). In this project, the scientific elements are contextualized to spark the interest and enjoyment of the user. This context is given by information in the app, but also information about proteins in the accompanying sticker book.

4. Method

4.1 The Body Bits app

In this project we only focus on a specific part of the app, but this paragraph explains the bigger picture – a rough sketch of what the app will look like.

In the app, proteins are presented in a simplified way to engage the target group (age 9-12). The app and sticker book will give the user information about physical and chemical aspects of proteins – what they look like and how they function – in a gamified way, hereby hopefully evoking interest in and maybe even (ultimately) a passion for science. Furthermore, the app connects proteins, food, and the human body.

The product works as follows: stickers with food and proteins are to be collected by the kids, similar to the "dinoplaatjes" from Albert Heijn (Mirande, 2016). These stickers contain a QR code that can be scanned by the app Body Bits. The QR code will only be scannable when the proteins are pasted next to the right food item. For example, for hemoglobin to function, iron is needed. The sticker of the hemoglobin protein can therefore be linked to the food stickers of food from which iron can be obtained, such as eggs, spinach, and seafood. This way, there is a challenge for the user to make the right connections.

When the sticker is scanned, the app will show more information about the protein, such as a 3D visualization of the structure or an illustration of the folding of the proteins. Next, the user must complete challenges with the proteins in order to let their character grow. This character is introduced when the app opens and guides the user on what to do and what the proteins do to the body of the character, and thus also to the body of the user. The implementation of the character in the app makes the connection clear between the proteins on the micro-level to the effects on the human body on the macro-level. For example, when the character is short on a protein that has a vital function for his well-being, the character tells the player that he is feeling unwell and hereby helps the player understand the effect of proteins on the macro-level.

The established learning objectives after playing the games in this app are:

- Cognitive goals:

After playing the games, the pupil is…

- … able to define and describe proteins and their functions in greater detail.
- … able to understand the function and importance of proteins.
- … able to relate proteins to their function in the human body and the body parts they affect.
- … familiarized with abstract thinking and thinking in models.

- Affective goals:

- After playing the game, the pupil feels excited and motivated to learn more about proteins and the human body.

Since learning about proteins are not part of the Dutch primary school children, these learning goals were stated by the project group in consultation with EPIC-XS at the start of the project. At this stage of the project, seven challenges with seven proteins that are important for the human body to function were contrived. The programmers that were part of the project group at this stage programmed the amylase challenge and the hemoglobin challenge. Since the amylase challenge was very simple, this project only focusses on the hemoglobin challenge.

4.2 The hemoglobin game

The function of the protein hemoglobin is explained to the user in a two-level game. Hemoglobin is displayed in the centre of the screen and can be rotated by the player by swiping on the depicted protein (see Figure 2). During the first level, the game takes place in the lungs, where there is an abundance of oxygen present, and a relatively smaller amount of carbon dioxide is present. In the game, oxygen molecules are indicated with red spheres and carbon dioxide molecules with blue spheres, both with faces on them. Both the larger amount of oxygen molecules and the small amount of carbon dioxide molecules are approaching the protein. The player is meant to rotate the protein in such a way that oxygen is bound to as many of the four active centres. However, the player will not always succeed to bind oxygen to all four active centres, as the player can only rotate the protein to a maximum of four times. This means that if a bond is made with carbon dioxide and the player turns the hemoglobin protein, the player can no longer rectify this. This limitation makes the game more difficult, thereby challenging the player. When oxygen is bound, a “happy” sound is played, whereas when carbon dioxide is bound, a “sad” sound is played, to help the player understand the goal of the game.

Figure 2: Screenshot of the app while playing the hemoglobin challenge.

At any time, the player can choose to click the “new hemoglobin’ button (see Figure 2). The hemoglobin protein that was previously played with, is then transported to the muscles. The player earns more points depending on how much oxygen is transported to the muscles. When enough points are earned, the player can click on “Go to the muscles”. The environment then changes to the muscles, where more carbon dioxide is present and also a small amount of oxygen, contrary to the situation in the lungs. A larger amount of carbon dioxide molecules (blue spheres) and a small amount of oxygen molecules (red spheres) approaches the protein. Now, the player must bind as many carbon dioxide molecules as possible.

In the second level, a new molecule is introduced: carbon monoxide. This molecule is indicated with a green sphere and blocks the protein from binding oxygen or carbon dioxide. When the game starts in the lungs, not only a larger amount of oxygen and a small amount of carbon dioxide are approaching the protein, but also an amount of carbon monoxide. If a carbon monoxide molecule is bound to an active centre, oxygen or carbon dioxide can no longer bind at this active centre. The player is meant to ensure that as little carbon monoxide as possible is bound to the hemoglobin, by rotating the protein. The way to achieve this is not explained in the game, in order to stimulate the player to actively come up with a solution for this problem. It is inevitable that at least one carbon monoxide molecule will bind, but the player can make sure that the rest of the green spheres that approach the protein, bind to the same active centre that has already been poisoned by carbon monoxide. This way, only one active centre is blocked and the other three are still available. This element is added to make the game challenging yet playable, however it is not true to how hemoglobin works in the human body – in the game, you can sacrifice one of the active sites to CO, while in reality, all of the four active sites will be poisoned. If this would have been implemented that way, the player would not be able to pass this level.

The established learning objectives after playing the game with hemoglobin are:

- Cognitive goals:

After playing the game with hemoglobin, the pupil is…

- … able to relate hemoglobin to its function in the human body and the body parts it affects.
- … able to identify how many active centres hemoglobin has.
- … able to identify what the colour of the molecule was that inhibited hemoglobin.

- … able to understand the importance of hemoglobin.
- … familiarized with abstract thinking and thinking in models.

- Affective goals:

- After playing the game, the pupil feels excited and motivated to learn more about proteins and the human body.

4.3 Evaluation through pilots by means of questionnaires and interviews

The approach that is chosen is that of qualitative research on a specific part of the prototype of the Body Bits app. The research question *To what extent does an augmented reality assisted protein app support primary school children (aged 9-12) in their understanding and engagement regarding proteins?* was investigated by means of surveys and interviews.

In the pilot, the pupils started by completing the first part of the questionnaire, played the game, and at the end completed the second part of the questionnaire. The first part of the survey consisted of 18 closed questions and the second part consisted of 10 closed questions and one open-ended question. Later, 7 pupils in total (3 for one participating school, 4 from the other participating school) were interviewed to gain in-depth insight into the experience the pupils had with the app and the knowledge they gained from it.

The target groups' gained knowledge from and experiences with the app were examined via questionnaires and interviews.

The learning aim is for children to be able to create connections between food, proteins, and their effects on the human body. Before playing the game, the participants were given a questionnaire that was designed to get to know the participants and their prior knowledge. Furthermore, to assess the learning of the target group using this product, a formative assessment was used to determine the effectiveness of the product and propose modifications in its design.

The first part of the questionnaire was designed to gather some background information about the participant and their prior knowledge. Here, the pupils are asked questions like how old they are, if they are male or female, whether he/she plays a lot of games, whether the pupil has been taught about science and technology at school and questions concerning their prior knowledge like knowing words as atoms, molecules, particles, and proteins. These factors may influence how well the pupil understands the game and how engaged the pupil is during the game.

After the first part of the questionnaire, the participants are given a phone with the Body Bits app installed. The researcher does not give any further explanation except that it is important that the pupils read the text that displays before and during the game. During this game, the students are allowed to ask questions, which are first answered with a hint and then possibly with more information.

In the second part of the questionnaire, the students answer questions about the game. An important part of this questionnaire is which concepts the pupils link to the game. For these questions, participants can choose from several concepts such as magnetism, attractions, molecules, and transport. It is interesting to know this, because we might be able to connect more closely to the pupils' prior knowledge or prevent misconceptions in a follow-up study. After this, the pupils are asked questions that test their understanding of the game. For example, does the pupil understand the difference between the game that is played in the lungs and the game that is played in the muscles? Do the students recall how many active centra hemoglobin had? Do they remember which colour of the molecules prevented other molecules from binding?

Interviews with 7 pupils that also participated in the questionnaire and the playing of the game were held to establish their prior knowledge and misconceptions on topics like proteins, molecules, and atoms. Furthermore, these interviews examined to what extent the target group can deal with abstraction, systems thinking, and thinking in scientific models. Lastly, the interviews were also used to assess whether the used language is understandable, the visualizations are engaging and the challenges within the Body Bits app are enjoyable. In summary the interview was designed to 1) further investigate the prior knowledge and capabilities of the participants, 2) investigate in detail what the participants learned, 3) examine what knowledge the participants remembered after 8 weeks, 4) determine whether the participants grew an interest in proteins or science in general because of the app.

4.4 Setting, participants, instruments, and data collection

The research took place at two schools during school hours. Participants played the game in an empty classroom with the researcher as observer. The questionnaires were designed in Qualtrics XM. The attempted male/female ratio is 1:1 and the pupils originated from grade 9, 10, 11 (groep 6, 7, 8).

In the organized pilot, the sample consisted of 16 pupils, of which 10 were male and 6 were female. The pupils originate from two schools in Amsterdam (10 pupils from one, 6 from the other). Of school 1, 8 participants were male and 2 were female. Of school 2, 2 participants were male and 4 were female. 9 pupils were in grade 11 (groep 8), 3 in grade 10 (groep 7) and 4 in grade 9 (groep 6). This research is to be regarded as a small-scale pilot.

The instruments that were used in this research were pre questionnaires, post questionnaires and interviews. Since the participants have not been taught about proteins in their primary education, no pre test was needed to establish extensive prior knowledge. Therefore, the pre questionnaire was used to get background information about the participants and their prior knowledge globally (sub-question 1) and the post questionnaire was constructed to examine whether the learning goals were reached (sub-question 3) and what the experience of the participants was while playing the game (sub-question 4). In the interviews, a more in-depth view was constructed on these topics, as well as an investigation on how well the target audience could deal with abstraction and scientific models (sub-question 2).

4.5 Data analysis

The interviews were coded bottom-up and the results of the questionnaires were analysed and visualised using Python. Since the sample size was small, no statistical tests were performed on the data. Because the interview consisted of questions comparable to the questions of the questionnaire – only then more in-depth – no top-down coding was needed. The interviews were coded afterwards by labelling relevant words, phrases or sections and counting how often they were said by the participants. The coding scheme can be found in the Appendix.

Using the scheme shown in Figure 3 by Baarda and de Goede, the type of questions that were interesting for this research were explored (Baarda & de Goede, 2006). Based on this scheme, the scheme in Figure 4 was constructed.

***Figure 3**: "From dimensions via indicators to questions" by Baarda & de Goede, 2006.*

Begrip	Dimensies	Indicatoren	Enquêtevragen
Emancipatie	→ Bijdragen aan huishoudelijk werk	→ Koken → De was doen →	→ Hoe vaak hebt u afgelopen week het eten gekookt? → Hoe vaak hebt u afgelopen week ....
	→ Bijdragen aan de opvoeding	→ Kinderen naar school brengen → Kinderen naar bed brengen →	→ Hoe vaak hebt u afgelopen week de kinderen naar school gebracht? → Hoe vaak hebt u afgelopen week ....
	→ Traditionaliteit opvattingen man	→ Opvattingen over vrouwen in leiding-gevende functies → Opvattingen over rolverdeling thuis →	→ In hoeverre vindt u het aanvaardbaar dat vrouwen op het werk leidinggeven? → .... → ....

Table 1: *Research question, concept, dimension and corresponding survey or interview questions.*

Research question	**Concept**	**Dimension**	**Survey/interview question**
What is the target group's prior knowledge and/or what are their misconceptions regarding proteins?	Prior knowledge; misconceptions.	The student is familiar with concepts related to proteins.	1. Have you ever heard of atoms, molecules, or particles? (Survey)
			2. Put the following concepts in order from smallest to largest: particles – atoms – molecules. (Interview)
			3. Have you heard of proteins? (Survey; interview)
			4. Do you know what a chemical substance is? (Interview)
			5. Do you know what a mixture is? (Interview)
			6. Of which concepts have you heard, and do you know what they mean (magnetism, electricity, attraction, repulsion, quantity)? (Survey)

			7. Of which concepts have you heard, and do you know what they mean (catalyst, protein, atom, blood, transport, molecule)? (Survey)
To what extent can the target group deal with abstraction and understand what scientific models are?	Abstraction; scientific models.	The participant is able to deal with abstract concepts.	1. Do you know what abstraction is? (Interview)
			2. Do you think the earth is round or flat? (Interview)
			3. Do you know what a scientific model is? (Interview)
			4. Can you give an example of a scientific model? (Interview)
			5. A) Do you think that an (object) is a scientific model (Object being a model airplane, a map of the world, a schematic figure of the layers of the earth, a schematic figure of DNA)? B) Why do you think this? (Interview)

Are the learning goals reached through playing the developed interactive game?	Learning goals.	The student knows the function of proteins in the body, in particular hemoglobin.	1. Why are proteins needed in the human body? (Interview) 2. What do you think the goal of the game is? (Survey, multiple-choice question; interview, open-ended question) 3. What difference did you see between the game you played in the muscles and in the lungs? (Survey, multiple-choice question; interview, open-ended question)
		The student knows how many active centres hemoglobin has.	How many active centres did the protein hemoglobin have in the game you played? (survey; interview)
		The student understands the concept of catalyst poisoning.	Which colour did the molecule have in the game that caused the protein to be blocked?
Is the developed game engaging for the target audience?	Engagement	The student enjoyed playing the game.	1. Did you enjoy playing the game with hemoglobin? (survey; interview) 2. What would have made the game even more fun or better? (survey; interview)
		The student is motivated to learn more about proteins.	1. Did you learn a lot from the game? (Survey; interview) 2. What did you learn from the game? 3. A) Would you like to know more about proteins and why they are needed in your body? B) Why is this? (Survey; interview)

5. Results and discussion

In this section, the results of the questionnaire and interviews will be discussed per subject. In section 5.1, it is discussed what was uncovered about the prior knowledge and misconceptions of the participants, addressing the first sub-question. In section 5.2, the second sub-question will be discussed, considering target group's ability to deal with abstraction and scientific models. Since there was no literature found on this topic, this issue was discussed rather extensively in both the interviews and the discussion of it. Subsequently, in section 5.3, the third sub-question will be addressed, discussing the target group's understanding of the game. Lastly, in section 5.4, the fourth sub-question will be addressed, in which the engagement of the participants will be discussed.

5.1 What is the target group's prior knowledge and/or what are their misconceptions regarding proteins?

5.1.1 Results from the post interviews

In the interview, participants were asked what the correct order from smallest to largest was for the concepts molecules, atoms, and particles. The concept of particles was included purposely because a particle can be an atom, molecule, or ion. This way, it was also tested whether the pupils knew that a particle does not belong in this sequence. 4 out of 7 of the interviewees thought the right order would be molecules, atoms, particles. The other 3 indicated an order proving they thought atoms were smaller than molecules. This means the majority of the participants did not know that atoms are smaller than molecules and no participants pointed out that particles do not belong in the sequence, proving they did not fully understand the meaning of the word particle.

As some other questions that will be discussed, the following question was not asked to all 7 participants, because it was added after two pilot interviews. In this question, 5 participants were asked what the relationship between molecules and atoms was. Here, 4 out of 5 of the participants answered that they did not know. Also 4 out of 5 of the participants confirmed that molecules are build of atoms when the interviewer said this. However, this result cannot be regarded as significant because they might as well have confirmed the opposite had the interviewer presented it in the opposite way. This tendency can also be described as the default bias and will be discussed more in detail in section 6.6.

All 7 participants answered positive when asked whether they had heard about proteins. When asked what they know about proteins, 4 out of 7 participants said that proteins are needed for something, without being able to specify for what. 2 out of 7 participants mentioned that proteins are healthy, and 2 others mentioned that proteins are present in eggs.

When asked if proteins are mixtures or consist of one substance, 5 out of 7 participants answered that they thought proteins are mixtures. This shows that the interviewees have not yet truly understood the concept of proteins. The ideas the participants have of the function of proteins differ. One participant said proteins are necessary for the heart to function and to pump blood (interviewee 4), one said proteins give energy (interviewee 5), and another said proteins heal muscles (interviewee 7).

5.1.2 Results from the post questionnaire

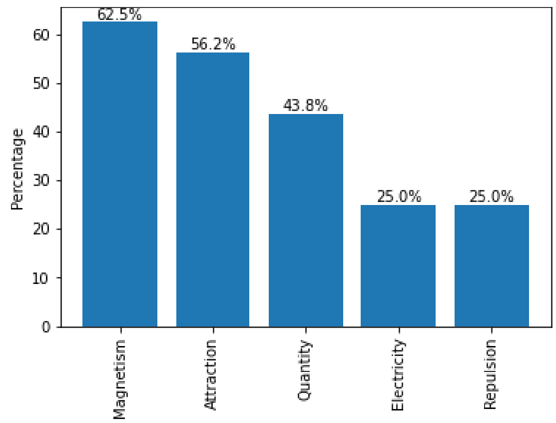

Figure 4: Concepts linked to the game of which the participant could choose in the first question.

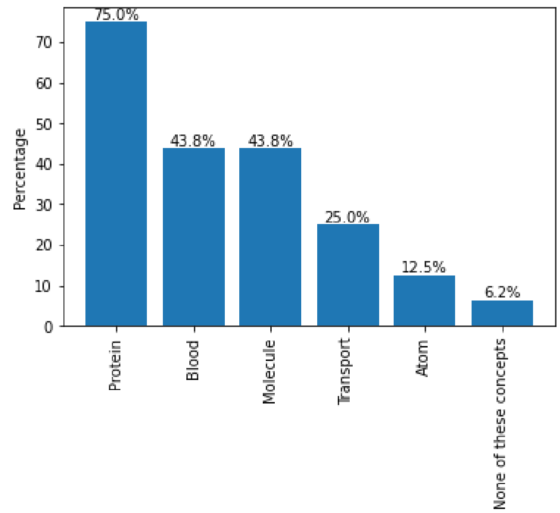

Figure 6: Concepts linked to the game of which the participants could choose in the second question.

After playing the game, pupils were asked via a questionnaire what concepts they thought would relate to the played game. However, this question was not included in the interview. This is unfortunate since this could have resulted in more insight in the construction of concepts regarding the topic.

In the first question (See Figure 5), 63% of the pupils indicated to have linked *magnetism* to the game, a characteristic property of all materials that contain electrically charged particles. Technically, molecules can be electrically charged particles and therefore this concept is not completely unrelated, but hemoglobin does not function due to magnetism. This concept is therefore not completely but quite unrelated to how the protein actually works. The same applies to the concept of *electricity*, which 25% of the participating pupils linked to the played challenge. However, 56% of the pupils linked *attraction* to the challenge, 44% linked *quantity* to the challenge, and 25% linked *repulsion* to the challenge. These concepts are strongly related to how the protein functions. For this question, no participant filled in the last option, namely: “none of the above-mentioned concepts are linked to the game”.

In the second question regarding conceptions that the participants could link to the game (See Figure 6), the options were *protein*, *blood*, *molecule*, *transport*, and *atom*. In this question, all the options were strongly related to how the protein Hemoglobin works – there was no wrong answer. This could have resulted in a default bias, as the only “wrong” option that the participant could choose would be the option “none of the above-mentioned concepts are linked to the game”. However, the results are still useful because it gives insight in what conceptions the participants link to the game. In this question, 75% of the participants linked *protein* to the game. This percentage is rather high, but when considered that the researcher gave a short introduction to the game mentioning it was about a protein, one could also have expected that *every* student had checked this option. Also, while the entire challenge takes place in the blood of the human body, only 44% linked *blood* to the game. Because hemoglobin is a molecule, the option *molecule* was also a correct answer, but only 44% linked this concept to the game. As molecules are made up of atoms, it would have made sense to check both of these boxes, but only 13% of the participants linked the concept *atom* to the game. Lastly, as the main function of Hemoglobin is to transport oxygen to the lungs, but only 25% of the participants linked the concept *transport* to the game.

5.2 To what extent can the target group deal with abstraction and understand what scientific models are?

This topic was only discussed in the interviews. In these interviews, the participants were asked questions about abstract concepts, to investigate to what extent they could deal with these. Some of these questions were added after the first two pilot interviews and therefore are only answered by 5 of the participants. First, they were asked if they know what abstraction means. Here, 1 of the 7 participants answered positively (interviewee 6) – he remembered hearing that art could be abstract. When asked what abstract art is, he said “Art with different shapes, and not like that poster hanging there or something.”, pointing to an educational poster hanging in the hallway. This participant therefore showed some idea what *abstraction* could mean, while the other 6 said they had no idea. When the interviewer explained the term abstraction to all 7 participants, they all nodded their head to show they knew what the interviewer meant.

Then, the participants (only the last 5 participants) were asked whether they thought the earth was flat or round. This question was meant to investigate their ability to deal with an abstract concept – they probably learned about the earth on television, via their parents or at school, but this is still an abstract concept. All 5 participants said the earth was round, and when asked why it is you cannot fall off the earth, 3 said that this is because of gravity. The other 2 did not mention gravity in their answer. When asked what gravity was, the 3 participants gave a naïve construction of this concept, ranging from “The reason we are not able to fly” (interviewee 5) to a better explanation “A mass that pulls as to the earth” (interviewee 6), to a more correct description “That's actually a kind of force that makes things fall down instead of floating around or going up” (interviewee 7).

Subsequently, the participants were asked if they knew what a scientific model was. Again, one of the 7 participants (interviewee 4) answered positively and said “A model… A kind of sketch, but it has already been made, and that is the first variant. And if it doesn't work, then you continue experimenting”. Although this explanation was quite impressive, the interviewer still gave the explanation of a scientific model that was also given to all other 6 participants. In this explanation, the researcher showed a molecular model as an example of a scientific model. Then, the participants were asked if they could name any other examples. Only 1 participant (interviewee 4) could name correct examples, saying: “Yes, I've seen some [scientific models] of the DNA, and molecules too. And bacteria, that sort of thing.” One other participant named a model airplane as a scientific model, but this is incorrect – while being a model, a model airplane is not a *scientific* model. The other 5 participants answered the question whether they knew other examples with “No”.

Then, the participants from the last 5 interviews were shown various examples while being asked whether this was a scientific model or not. Here, 4 out of 5 participants thought a model airplane was a scientific model, which is incorrect. When asked why, the one participant that answered that a model airplane was not a scientific model (interviewee 3) said: “Because it has nothing to do with science. And you can just see it.” While it is not completely correct that an airplane has got *nothing* to do with science, it is indeed correct that an airplane has more to do with technology than with science. Furthermore, a model airplane is not made to show the science behind an airplane – sometimes it is purely a collector’s item, sometimes it is used to show how the technology of the airplane works or what the design looks like, but it is never used as a scientific model. From the other 4 participants that did not think the model airplane was a scientific model, 3 gave the reason that you can see an airplane in real life, so it is not a scientific model. While the answer that it is not a scientific model is true, the reason the participants gave is incorrect. Not being able to see the scientific phenomenon with the naked eye is not a condition for a scientific model.

The next item that was shown to the participants was a map of the world. Here, 4 out of the 5 participants answered that they thought this was a scientific model, which is incorrect. The map of the world does contain information about the world while not being a direct image of it, but it is not a theoretical model that shows the science of the earth. Their reasons for their answer differed from "Because you cannot see the whole earth [with your naked eye], but on the map you can" (interviewee 3 and 7) to "Because it was made to show what the earth looks like" (interviewee 4, 5, and 6).

The item that was shown next was a picture of the layers of the earth. Again, here, 4 out of the 5 participants thought that this was a scientific model. The participant that did not think this was a scientific model, said: "Because it does not show the whole earth" (interviewee 3). The reasons the other participants gave for the picture being a scientific model differed from "Because it is a milestone in science" (interviewee 4), to "Because people saw this in real life" (interviewee 5), to "Because we would not have know this if nobody had ever researched it" (interviewee 6), and to "Because it is something that my teacher could have explained in science class" (interviewee 7).

Lastly, the participants were shown a picture of DNA. Here, all 5 participants said that they thought this was a scientific model. 4 of them gave the reason "Because DNA is small, and you cannot see it in real life". This is an interesting remark that was also observed in the answers about the model airplane, the map of the world, and the layers of the earth. The participants seemed convinced that something can only be a scientific model if it cannot be seen with the naked eye.

However, since only one of the participants knew the definition of a scientific model beforehand, this could be due to the explanation given by the researcher. In the explanation the researcher said: “A scientific model is another way of representing reality. For example, a molecule is too small to see with the naked eye, but we do know what molecules look like. This is, for example, a model of a piece of a protein (interviewer shows a model of a protein at this moment). It's called a model because it's a simpler picture of what the protein actually looks like. People make scientific models to better understand how the world works; in this example I can use this scientific model to explain how a protein works.” While this explanation was correct, the participants seemed to have remembered the given example in particular and have made all their subsequent statements depending on that example. For follow-up research that would also focus on this aspect, being abstraction and scientific models, it is therefore advised to emphasize that this is just an example and to also give another example, particularly one that can be seen with the naked eye.

5.3 Are the learning goals reached through playing the developed interactive game?

5.3.1 Results from the post questionnaire

Questions 23, 24, 25 and 26 of the post questionnaires were multiple-choice questions that tested how well the participants understood the game. In question 23, the participants were asked what the function of hemoglobin was, in question 24 they were asked what the difference was between the situation in the lungs and the muscles, in question 25 they were asked how many active centres hemoglobin had and in question 26 they were asked what colour of the molecules that approached the protein was the one that inhibited the protein.

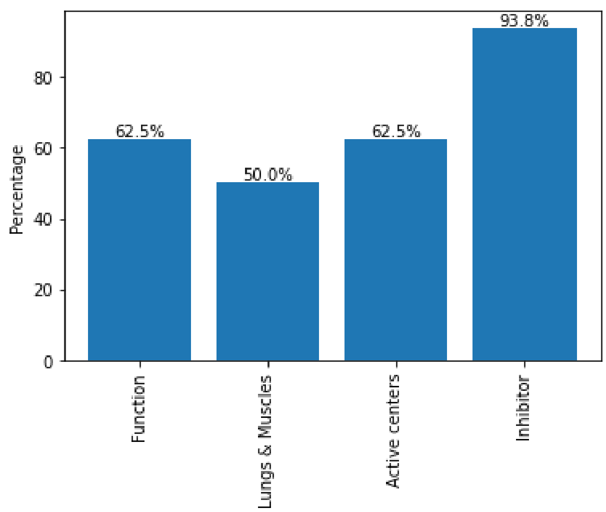

***Figure 7**: Percentages of the number of participants that answered the question about the goal of the game, the difference between the game in the lungs and in the muscles, the number of active centres and the question about the colour of the molecule that inhibited hemoglobin right.*

As can be seen in Figure 7, 10 out of 16 pupils (63%) answered the question 23, which was about the function of hemoglobin, right. For question 24, this was a bit lower, 8 out of 16 (50%) answered the question, which was about the difference between the situation in the lungs and the muscles, right. Since these two questions measured the first learning goal, it is also valuable information that 6 participants answered both these questions right, and 6 other participants answered either question 23 or question 24 right. For question 25, 10 out of 16 participants (63%) answered the question right, this question was about the number of active centres present in hemoglobin. The question that was answered right by the most pupils is question 26, which was about the colour of the molecule that inhibited the protein. 14 out of 16 pupils (88%) answered this question right.

In Figure 8, 3 pupils (19%) answered 1 question out of 4 correctly, 3 pupils (19%) answered 2 out of 4 questions correctly, 6 pupils (38%) answered 3 out of 4 questions correctly and 4 pupils (25%) answered all 4 questions correctly.

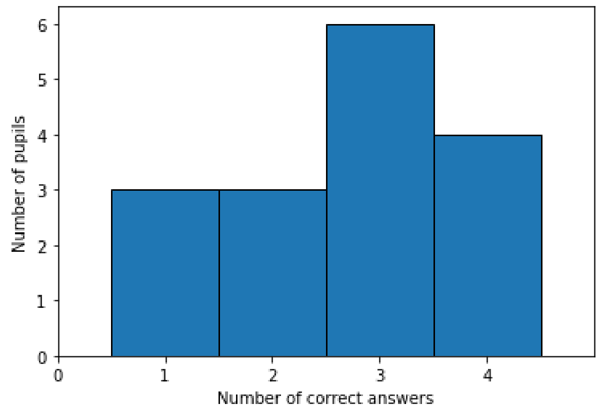

***Figure 8**: The number of participants that gave a certain number of correct answers*

In Figure 9, the difference in understanding between male and female participants can be seen. For question 23, the question about the goal of the game, 6 out of 10 (60%) of the male participants answered right, whereas 4 out of 6 (67%) of the female participants answered right. For question 24, which was about the difference between the situation in the lungs and the muscles, 4 out of 10 (40%) of the male participants answered right, while 4 out of 6 (67%) out of the female participants answered right. For question 25, which was about the number of active centres that were present in hemoglobin, 7 out of 10 (70%) of the male participants answered right, where on the other hand 3 out of 6 (50%) of the female participants answered right. Question 26, which was about the colour of the inhibiting molecule carbon monoxide, 9 out of 10 (90%) of the male participants answered right, whereas 6 out of 6 (100%) of the female participants answered right.

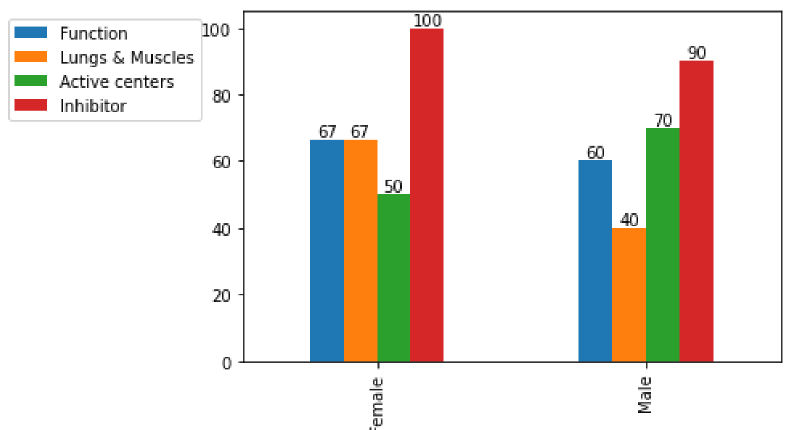

***Figure 9:** The difference between the male and female participants in answering each question correctly.*

In Figure 10, the difference in understanding between the participants from the two different schools can be seen. For question 23, 7 out of 10 (70%) of the participants of school 1 answered right, while 3 out of 6 (50%) of the participants of school 2 answered right. For question 24, 6 out of 10 (60%) of the participants of school 1 answered right, whereas 2 out of 6 (33%) of the participants of school 2 answered right. For question 25, 6 out of 10 (60%) of the participants of school 1 answered right, while 4 out of 6 (67%) of the participants of school 2 answered right. Question 26, 9 out of 10 (90%) of the participants of school 1 answered right, where on the other hand 6 out of 6 (100%) of the participants of school 2 answered right.

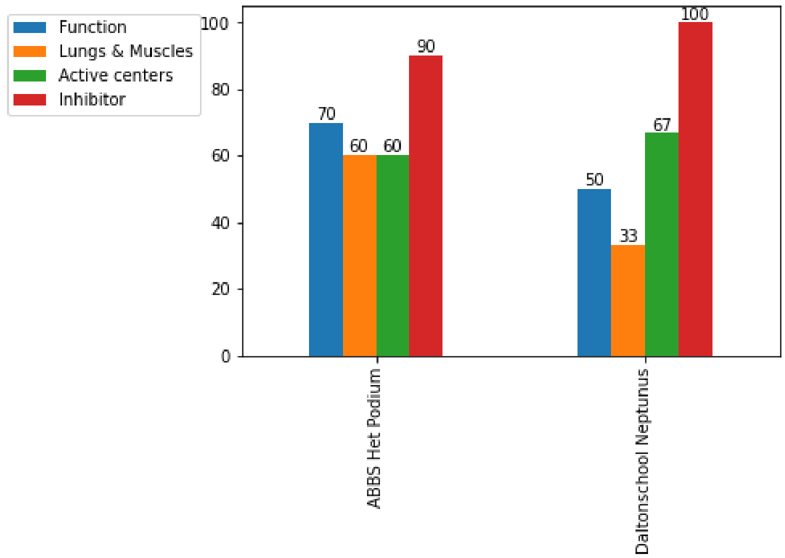

***Figure 10**: The difference between the participants from the two participating schools in answering each question correctly.*

5.3.2 Results from the post interviews

Eight weeks later, the pupils were asked in an interview what they learned from the game. Unfortunately, 4 out of the 7 participants answered in a way that proved that they did not remember what they learned. One of the other 3 participants answered that it was about red, blue, and green blood substances (interviewee 1), another answered they learned that several things have to do with proteins (interviewee 6), and another answered that they learned what substances are good to have in your lungs (interviewee 7). No participant could indicate what the difference was between the game played in the lungs versus the muscles. However, 5 out of the 7 participants remembered that there were four active centra in hemoglobin and 6 out of 7 remembered that the colour of the blocked molecule was green. This aspect of the game thus seems to have made an impression on the participants.

5.4 Is the developed game engaging for the target audience?

5.4.1. Results from the post questionnaire

Figure 11 shows how the participants experienced the game. Here, 50% of the participants (8 out of 16), indicated that they found the game fun to play. 25% indicated that they found the game very fun to play and 12.5% indicated that they did not find the game fun. Another 12.5% indicated that they found the game a little fun. No students indicated that they disliked playing the game (option number 5: "Ik vond het spelletje heel stom om te spelen").

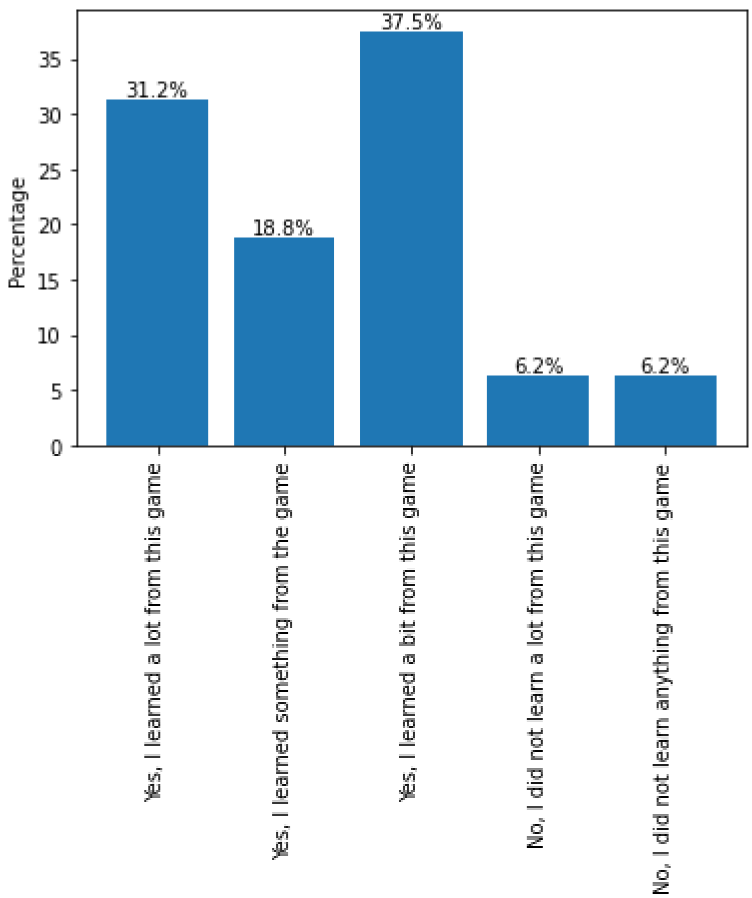

***Figure 11**: Percentages of the participants that indicated how fun the game was (indicated on a Likert scale).*

In the interviews, participants were asked about their experience with the game in more detail. Here, 5 out of 7 participants said they thought the game was fun to play. Reasons interviewees gave for liking the game were that the game was challenging (2 participants), the game was informative (2 participants), or the game resulted in them being able to imagine how this would happen inside of their body (1 participant).

When asked in the questionnaire whether the participants learned something from the game (See Figure 12), 38% of the participants (6 out of 16 participants) answered that they learned a little from the game, 31% (5 out of 16) participants answered that they learned a lot from playing the game, while 19% (3 participants) answered they learned something from the game. 1 participant answered they did not learn anything from the game and 1 other participant answered they did not learn a lot from the game.

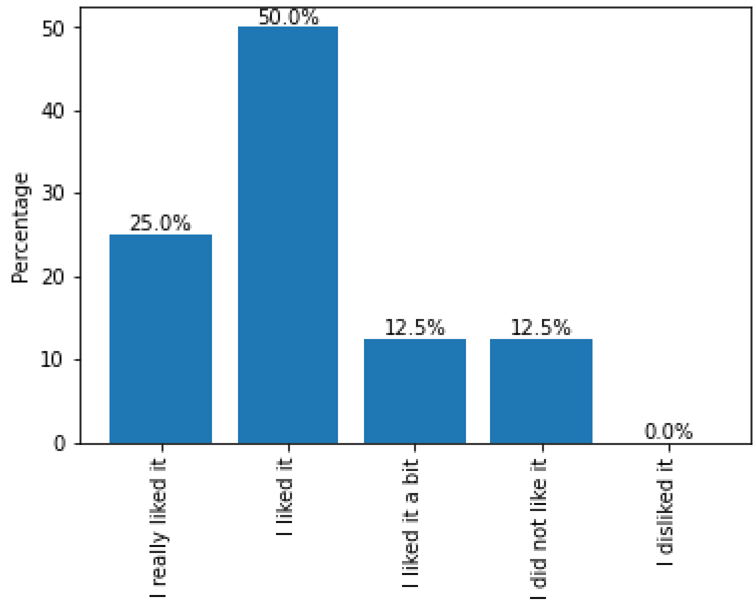

***Figure 12**: Percentages of the participants that indicated how much they learned during the game (indicated on a Likert scale).*

5.4.2 Results from the post interviews

When asked in the interviews though, most participants (5 out of 7) could not remember what it was they learned in the game. When asked if they wanted to learn more about proteins however, all 7 participants answered positively. 6 of them indicated the reason for wanting to know more was the game they had played with hemoglobin.

6. Conclusions

In this section, conclusions to the research question are drawn by first answering each sub-question one by one. In section 6.5 the main research question will be discussed, in section 6.6 the limitations of the study or discussed, and in section 6.7 suggestions for follow-up studies are made.

6.1 What is the target group's prior knowledge and/or what are their misconceptions regarding proteins?

The target group's prior knowledge regarding proteins is limited. Most of the participating pupils have heard of concepts like atoms, molecules, particles, and proteins, but when asked for a description, most give an incorrect, incomplete, or vague answer. Most participants knew proteins are important for the human body to function, but only 4 of them were able to specify for what. This shows that however the participants have heard about these concepts, they do not fully understand them.

For example, when asked for the right order from smallest to largest of the concepts molecules, atoms, and particles, 3 out of 7 gave an answer in which they showed that they thought atoms were smaller than molecules, which is correct. However, the other 4 gave orders proving they thought atoms were larger than molecules. Furthermore, since no participants pointed out that particles do not belong in the sequence, this proves that the participants do not fully understand the meaning of the word particle.

When having played the game, pupils link incorrect concepts to the hemoglobin challenge. For example, 63% of the pupils linked *magnetism* to the game and 25% linked *electricity* to the game, both concept that are only vaguely related to how the protein actually works. This shows that, even after playing the game, the pupils still have misconceptions about how the protein functions.

From section 6.1 and this section, it can be concluded that it is positive that the participants recognize the concepts that come along in the BodyBits app. However, it can also be concluded that the participants might need more guidance than the app gives in the state that it is now in.

6.2 To what extent can the target group deal with abstraction and understand what scientific models are?

From the interviews, it can be concluded that the pupils can deal with abstraction to a certain extent, as they, for example, have thought about topics like if the earth is flat or round. They could also answer questions about scientific models with reasoning that were incorrect, but made sense, considering the information they were given at that time. This can be seen as an indicator that the participants are ready for challenging, abstract concepts like proteins.

Furthermore, although the interviewer did explain what a scientific model was, the pupils proved to have not understood this concept fully, as they categorized some items as scientific models whilst this was false or gave incorrect reasons (although sometimes categorizing the item rightfully).

The remark that something can only be a scientific model if it cannot be seen with the naked eye, was observed when the participants were asked about a model airplane, the map of the world, the picture of the layers of the earth, and a picture of DNA. It can therefore be concluded that pupils can appreciate a certain level of abstraction, but that instructions must be very clear in order to avoid misconceptions.

6.3 Are the learning goals reached through playing the developed interactive game?

The learning goals that were to be achieved after playing the games in the app, as stated in section 4.1, were:

- Cognitive goals:

After playing the games, the pupil is…

1. … able to define and describe proteins and their functions in greater detail.
2. … able to understand the function and importance of proteins.
3. … able to relate proteins to their function in the human body and the body parts they affect.
4. … familiarized with abstract thinking and thinking in models.

Affective goals:

5. After playing the game, the pupil feels excited and motivated to learn more about proteins and the human body.

In the interview, pupils did not show that they were able to define and describe proteins and their function in greater detail (learning goal 1). They did understand the importance of proteins for the human body but did not understand the function of these proteins (learning goal 2). They were not able to relate proteins to their function and the human body and the body parts they affect (learning goal 3). However, the participants were familiarized with abstract thinking and thinking in models (learning goal 4). This learning goal was not measured, since the participants are automatically familiarized with these skills when playing the games in the app, in this case the game with hemoglobin. Furthermore, all interviewees were excited and motivated to learn more about proteins and the human body (learning goal 5).

The learning goals after playing the game with hemoglobin, as stated in section 4.2 were:

- Cognitive goals:

After playing the game with hemoglobin, the pupil is…

1. … able to relate hemoglobin to its function in the human body and the body parts it affects.
2. … able to identify how many active centres hemoglobin has.
3. … able to identify what the colour of the molecule was that inhibited hemoglobin.
4. … able to understand the importance of hemoglobin.
5. … familiarized with abstract thinking and thinking in models.

Affective goals:

6. After playing the game, the pupil feels excited and motivated to learn more about proteins and the human body.

From the results of the questionnaire, it can be concluded that 6 out of 16 participants reached the goal about hemoglobin and its function and the body parts it affects fully, and 6 other participants reached this goal partly (learning goal 1). Next, 10 out of 16 participants could identify how many active centres hemoglobin has (learning goal 2). Furthermore, 15 out of 16 participants could identify the colour of the molecule that inhibited hemoglobin (learning goal 3). The fourth learning goal, being able to understand the importance of hemoglobin, was not measured in the questionnaire. From the interviews, it can be concluded that none of the 7 interviewed participants could identify the importance of hemoglobin. However, the fifth learning goal, being the same as the fourth learning goal from section 4.1, was reached. The sixth learning goal, being the same as the fifth learning goal from section 4.1, was also reached.

However, 8 weeks later in the interview, 4 out of 7 participants did not remember the function of hemoglobin anymore and the other three only gave a vague description, so all 7 participants showed no excessive understanding of the function of hemoglobin after not having played it for 8 weeks (learning goal 1). Also, none of the 7 participants in the interviews remembered the difference between the game in the lungs and in the muscles (learning goal 2).

There were however two other important pieces of information that most pupils did remember after 8 weeks. In the questionnaire, 63% (10 out of 16) of the participants answered the question about the number of active centres present in hemoglobin right and 88% (15 out of 16) answered the question about the colour of the molecule that inhibited the protein right. In the interview 8 weeks later, 5 out of the 7 participants remembered that there were four active centra in hemoglobin and 6 remembered that the colour of the blocked molecule was green. This aspect of the game seems to have made an impression on the participants.

Thus, it can be concluded that some learning goals were achieved initially, but pupils were unable to retain this knowledge for 8 weeks. It would therefore be useful to focus on this problem in follow-up research – how can the target group be aided to retain this knowledge for a longer period, or even internalize the knowledge? It is hypothesized that two factors can benefit the target group, of which the first is simply more repetition. The game is meant to be played repeatedly, while in this research, the pupils only played the game for 15 to 30 minutes. The second suggestion that also emerged from the feedback of the participants, is to equip the game with more and better explanations or even videos that explain more about the protein.

Although the pupils showed quite some understanding of proteins right after the game, 8 weeks later when the interview took place, they forgot information such as what they learned from the game, what the function of hemoglobin was, and what the difference was between the game played in the lunges or the muscles. They generally did however remember that the catalyst had 4 active centres and that the green molecules inhibited the catalyst. It is hypothesized that the pupils either need more information on the topic or more repetition to retain this newly acquired knowledge on a long-term scale.

6.4 Is the developed game engaging for the target audience?

In general, the game seemed to be engaging for the target audience. From the questionnaires and interviews, it can be concluded that the target audience does find the topic interesting and are indeed “ripe” for it to a certain extent. They become curious about the subject and want to know more about it, which was one of the main goals of the research. However, to make the actual information come across better, more research is needed – what exactly can the students deal with? What more information do they need to really understand how the protein works? What makes the knowledge stick better? Is that just repetition or is more or better explanation needed in the app?

6.5 To what extent did an augmented reality assisted protein app support primary school children (aged 9-12) in their understanding and engagement regarding proteins?

From section 6.1, it can be concluded that the target group's prior knowledge regarding proteins is limited. Furthermore, the participants link incorrect concepts to the hemoglobin challenge. Therefore, it can be concluded that the participants are familiar with the concepts related to the hemoglobin challenge but need more guidance than the app provides. As discussed in section 6.2, the participants can deal with abstract concepts to a certain extent but need clear instructions to do so. Although the interviewer explained what scientific models are, the pupils still proved unable to understand this concept fully. The questionnaire showed that 6 out of 16 participants had 3 out of the 4 questions right were meant as a formative assessment, 4 participants had 4 questions right and 6 participants had less than 3 questions right, as discussed in section 6.3 (see also section 5.3). This is considered to be a reasonably high score for pupils who have not been taught about proteins before. However, 8 weeks later in the interview, 4 out of 7 participants did not remember the function of hemoglobin anymore and the other three only gave a vague description, so all 7 participants showed no excessive understanding of the function of hemoglobin after not having played it for 8 weeks.

There were however two other important pieces of information that most pupils did remember after 8 weeks. In the interview, 5 out of the 7 participants remembered that there were four active centra in hemoglobin and 6 remembered that the colour of the blocked molecule was green. Thus, it can be concluded that some learning goals were achieved initially, but the participants were unable to retain this knowledge for 8 weeks.

In general, the game seemed to be engaging for the target audience, as discussed in section 6.4. The participants were excited to play the game and did not want to stop playing it. The target audience thus does find the topic interesting and are indeed "ripe" for it to a certain extent. However, to make the actual information come across better, more research is needed.

6.6 Limitations

In this project, a qualitative research with 16 participants was conducted, including in-depth interviews with seven participants. The insights this research gave were valuable but could have been more valuable if the research was performed with more participants. Also, although the initial idea for this project was to be used in an informal context, this research was conducted at two primary schools, so in a formal context. The engagement of the students in this context is an indicator for the engagement the students would have in an informal context, but the excitement of the participants can also be explained by the fact that the participants were allowed to play a game during school hours.

Furthermore, some questions in the questionnaires and interviews are formulated in a too directing way; students could often choose from many correct, some near-correct and 1 or 2 incorrect answers. Also, in the interview the interviewer first asked, "What do you think atoms and molecules have to do with each other", and then asked the four participants that did not know the answer to this question "Do you think molecules are build of atoms?". All 4 participants then confirmed this, but because the question was so directing this data is likely the result of a default bias.

6.7 Follow-up studies

This research gave many insights in how to approach follow-up research. For example, future studies should investigate preferably with more participants and should explore other contexts, while this research project only focussed on formal education. Subsequently, the prior knowledge of the target group should be determined better and more extensively. This investigation of the prior knowledge of the target audience could for example result in a more extensive explanation in the app, which is more tailored to the target group's perspective.

Also, data was attempted to be obtained from questionnaires with the teachers that teach the participants, but since only one of the two teachers responded, this data was discarded. Because this might be of relevance for follow-up research, the questionnaire is nonetheless included in the appendix. This questionnaire was designed to investigate whether the lesson style of the teacher is of influence on the learning habits of the participants, and therefore also the efficacy of the app.

Furthermore, the accompanying sticker book could be developed. This sticker book could provide the target group with more in-depth explanation on the proteins. Lastly, games with different proteins could be explored. Interesting questions rise when a different protein is the topic of the game – are those games just as exciting? Are they more or less suitable for the target group? Does it match their experience or prior knowledge more or less than playing the game with hemoglobin? Are there, just like in this research, learning goals that the students achieve at first, but have forgotten after a few weeks?

References

Bouffard, T., & Vezeau, C. (1998). *Self-awareness: Its nature and development* (R. J. Ferrari, M. & Sternberg (ed.); pp. 246–272).

Cakir, M. (2008). Constructivist approaches to learning in science and their implication for science pedagogy: A literature review. *International Journal of Environmental and Science Education*, *3*(4), 193–206.

Chiarelott, L., and Czerniak, C. (1987). Science anxiety: Implications for science curriculum and teaching. *The Clearing House*, *60*(5), 202–205. https://doi.org/https://doi.org/10.1080/00098655.1987.9959323

Chytas, D., Johnson, E. O., Piagkou, M., Mazarakis, A., Babis, G. C., Chronopoulos, E., Nikolaou, V. S., Lazaridis, N., & Natsis, K. (2020). The role of augmented reality in Anatomical education: An overview. *Annals of Anatomy*, *229*, 151463. https://doi.org/10.1016/j.aanat.2020.151463

Dorion, K. (2011). A learner's tactic: How secondary students' anthropomorphic language may support learning of abstract science concepts. *Electronic Journal of Science Education*, *12*(2), 1–22.

Dweck, C. S. (1986). Motivational Processes Affecting Learning. *American Psychologist*, *41*(10), 1040–1048. https://doi.org/10.1037/0003-066X.41.10.1040

Gelman, S. A., & Noles, N. S. (2011). Domains and naïve theories. *Wiley Interdisciplinary Reviews: Cognitive Science*, *2*(5), 490–502. https://doi.org/10.1002/wcs.124

Gilbert, J. (2006). On the nature of 'context' in chemical education. *International Journal of Science Education*, *28*(9), 957–976. https://doi.org/10.1080/09500690600702470

Gottfried, A. E. (1990). Academic Intrinsic Motivation in Young Elementary School Children. *Journal of Educational Psychology*, *82*(3), 525–538. https://doi.org/10.1037/0022-0663.82.3.525

Kalogiannakis, M., Papadakis, S., & Zourmpakis, A.-I. (2021). Gamification in Science Education. A Systematic Review of the Literature. *Education Sciences*, *11*(1), 22. https://doi.org/10.3390/educsci11010022

Kerr, S. C., & Walz, K. A. (2007). 'Holes' in student understanding: Addressing prevalent misconceptions regarding atmospheric environmental chemistry. *Journal of Chemical Education*, *84*(10), 1693–1696. https://doi.org/10.1021/ed084p1693

Klopfer, E., & Squire, K. (2008). Environmental Detectives — The development of an augmented reality platform for environmental simulations. *Educational Technology Research and Development*, *56*(2), 203–228. https://doi.org/10.1007/s11423-007-9037-6

Lazarowitz, R., & Lieb, C. (2006). Formative Assessment Pre-Test To Identify College. *International Journal of Science and Mathematical Education*, *April 2005*, 741–762.

Mallow, J. V. (1978). A science anxiety program. *American Journal of Physics*, *46*(8), 862–862. https://doi.org/10.1119/1.11409

Marbach-Ad, G. (2001). Attempting to break the code in student comprehension of genetic concepts. *Journal of Biological Education*, *35*(4), 183–189. https://doi.org/10.1080/00219266.2001.9655775

Mirande, R. (2016). *Albert Heijn komt met virtual reality Dino-spaaractie*. https://www.adformatie.nl/digital-transformation-tech/albert-heijn-komt-met-virtual-reality-dino-spaaractie

Norris, S. P., & Phillips, L. M. (2003). How Literacy in Its Fundamental Sense Is Central to Scientific Literacy. *Science Education*, *87*(2), 224–240. https://doi.org/10.1002/sce.10066

Piaget, J. (1929). *The Child's Conception of the World: A 20th-Century Classic of Child Psychology*. Routledge.

Reiss, M. J., & Tunnicliffe, S. D. (1999). Conceptual development. *Journal of Biological Education*, *34*(1), 13–16. https://doi.org/10.1080/00219266.1999.9655677

Reiss, M. J., Tunnicliffe, S. D., Andersen, A. M., Bartoszeck, A., Carvalho, G. S., Chen, S. Y., Jarman, R., Jónsson, S., Manokore, V., Marchenko, N., Mulemwa, J., Novikova, T., Otuka, J., Teppa, S., & Van Rooy, W. (2002). An international study of young peoples' drawings of what is inside themselves. *Journal of Biological Education*, *36*(2), 58–64. https://doi.org/10.1080/00219266.2002.9655802

Ryan, R. M., & Deci, E. L. (2000). Self-determination theory and the facilitation of intrinsic motivation, social development, and well-being. *American Psychologist*, *55*(1), 68–78. https://doi.org/10.1037/0003-066X.55.1.68

SLO. (2018). *Wetenschap & technologie in het basis- en speciaal onderwijs*. https://www.slo.nl/thema/meer/wetenschap/leerplankader/

Turkmen, H., & Usta, E. (2007). The role of learning cycle approach overcoming misconceptions in science. *Kastamonu Education Jurnal*, *15*(2), 491–500.

van Roy, R., & Zaman, B. (2017). Why gamification fails in education and how to make it successful: Introducing nine gamification heuristics based on self-determination theory. *Serious Games and Edutainment Applications: Volume II*, *II*, 485–509. https://doi.org/10.1007/978-3-319-51645-5_22

Watts, M., & Bentley, D. (1993). Humanizing and feminizing school science: Reviving anthropomorphic and animistic thinking in constructivist science education. *International Journal of Science Education*, *16*(1), 83–97. https://doi.org/10.1080/0950069940160106

Wilson, L. M., & Corpus, D. A. (2001). The Effects of Reward Systems on Academic Performance. *Middle School Journal*, *33*(1), 56–60. https://doi.org/10.1080/00940771.2001.11495578

Wood-Robinson, C., Lewis, J., & Leach, J. (2000). Young people's understanding of the nature of genetic information in the cells of an organism. *Journal of Biological Education*, *35*(1), 29–36. https://doi.org/10.1080/00219266.2000.9655732

Wu, H. K., Lee, S. W. Y., Chang, H. Y., & Liang, J. C. (2013). Current status, opportunities and challenges of augmented reality in education. *Computers and Education*, *62*, 41–49. https://doi.org/10.1016/j.compedu.2012.10.024