Understanding Diffusion and Osmosis by making Drawing-Based Models

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Abstract

The study investigated reasoning process of students who modeled the processes of diffusion and osmosis with the program SimSketch. To be able to use SimSketch for the subject of diffusion and osmosis, some software and an assignment had to be designed. Five 4 vwo students were recorded while going through the assignment and the extra questions about their understanding of models and their opinion of SimSketch. These quotes were coded in five categories: *Understanding of SimSketch*, *Prior knowledge activation*, *Reasoning*, *Newly gained knowledge* and *Learning due to SimSketch*. From the model-understanding questions, it became clear the students know a model to be a hypothetical representation of the real world, instead of a replica. This helped them to see SimSketch as a model and to compare this model with the real world and the knowledge the students already possessed about diffusion and osmosis. Most basic knowledge was still known by the students, additional knowledge was obtained from the researcher, from the results visible in SimSketch and by reasoning. While modelling, this knowledge was used by the students to explain if and why they thought a new situation was more like the original, they were able to make an assessment and formulate arguments to support this. Drawing-based modelling for this matter helped the teacher to discover the faults and possible misconceptions of the students more easily since those are more visible. Not only the teacher but also the students seem to discover their faults more easily thanks to drawing-based modelling since they are corrected by the effects of their own settings.

Models and modelling play a key role in science. Models provide a representation of systems and phenomena, and are used to construct and test research questions and hypotheses (Gilbert, 1995; NRC, 2012). It has also been shown that a model can lead to a better understanding and visualisation of the modelled physical phenomena (NRC, 2012). The positive effect of modelling, to increase the understanding of certain processes, has already been demonstrated (Baek, Schwarz, Chen, Hokayem, & Zhan, 2011; Grünkorn, zu Belzen, & Krüger, 2014; Louca & Zacharia, 2015; Schwarz et al., 2009). The structure of the subject will be clearer for students who created models during their classes (van Borkulo, van Joolingen, Savelsbergh, & de Jong, 2011). Therefore, it is not remarkable for research in science education to acknowledge the importance of models and modelling in the development of scientific literacy (Gilbert, 1991; Gilbert, Boulter, & Rutherford, 1998; Linn, 2003; Linn, & Muilenburg, 1996; Perkins, 1986).

Concerning all possible modelling tools, computer-based models turn out to lead to the more advanced models of physical phenomena than other non-dynamic modelling tools (e.g., paper and pencil) (Louca & Zacharia, 2008, 2015; Louca, Zacharia, Michael, & Constantinou, 2011; Fretz et al., 2002; Penner, 2001; Stratford, 1997; Windschitl, 2000). Constructing models instead of only interpreting them also enlarges the understanding of the original, by participating in the modelling process, learning moves from ‘learning with models’ to ‘learning by modelling’ (Milrad, 2004). But it has also become clear that most students who have worked with modelling tools found it difficult to learn the programming language (Bollen & van Joolingen, 2013). In these modelling tools, such as Coach 7 (cma-science, 2017) and Stella (Isee systems, 2017), a modelling language is used that is comparable with programming language. The drawing-based models in SimSketch resolve this problem and make it possible even for younger children to experience the positive effects of model-based learning (van Joolingen, Aukes, Gijlers, & Bollen, 2015).

SimSketch is a modelling tool that makes it possible for students to design their own model, using their own drawings as objects. Users are able to attach behaviour(s) to the object with the help of drag-and-drop tools. SimSketch was aimed to "support essential reasoning processes such as identifying model components, their properties and behaviour in an intuitive way" (van Joolingen et al., 2015, p. 2). Since SimSketch is a lot easier to use than other modelling tools, SimSketch is a software with promising in-class possibilities also with younger students (van Joolingen et al., 2015).

In this study, SimSketch will be used in a newly designed lesson to teach the biology subjects of diffusion and osmosis. Diffusion and osmosis are concepts which are very important to the understanding of basic biology concepts. Unfortunately for many students, the principles of diffusion and osmosis are complicated and hard to understand (Odom, 1995; Tarakçi, Hatipoğlu, Tekkaya, & Özden, 1999; Zuckerman, 1994). A certain number of simulations have been designed to give students insight into those molecular processes, but less is known about the reasoning process the students go through. We do know about a number of possible misconceptions from which we could deduce some of the reasoning process students go through, but that is far from enough. Therefore, the aim of this study is to see if SimSketch can support learners' reasoning process of diffusion and osmosis.

Theoretical Framework

Models

Models are important while developing scientific literacy, but what is a model? A model is a simplified representation of the reality. They are used for a lot of purposes and have many different appearances. Thanks to its wide use and diversity, a lot of definitions have been proposed to describe a model. A general definition of a model is given by Rothenberg (1989):

> "Modelling, in its broadest sense, is the cost-effective use of something in place of something else for some purpose. It allows us to use something that is simpler, safer or cheaper than reality instead of reality for some purpose. A model represents reality for the given purpose; the model is an abstraction of reality in the sense that it cannot represent all aspects of reality. This allows us to deal with the world in a simplified manner, avoiding the complexity, danger and irreversibility of reality." (p. 1)

In education and in daily life all kinds of models are used, from simple drawings of graphs up to complicated scale models or simulations. In education, those models are used to visualise and simplify reality (Gilbert et al., 1998). Although this simplification does often not represent all aspects of reality (Rothenberg, 1989), it does make it easier to understand for the students without the complexity, danger and irreversibility of reality.

According to Linn (2003), those visualisations could also have a confusing rather than an informing effect. This is because learners lack the background knowledge held by the constructors of the model, making interpreting the model correctly more challenging. However, because models are simplifications which make them more accessible for students (Gilbert et al., 1998) and because models are important to understand the nature of scientific advance today, it is important for students to make sense of the modelling process (Gilbert et al., 1998; Linn, 2003).

Besides the importance in daily life to understand a model and a modelling process, in every branch of science, research programs are based on models of scientific phenomena. Which makes most emerging disciplines in science require their scientists to be able to improve, create, test and revise models and model systems (Linn 2003).

In this study, a model is used for the visualisation of a simplified representation. Students construct, test and revise models in SimSketch to gain a deeper understanding of the subjects diffusion and osmosis. Since the students have to model all the elements in SimSketch and set all the setting themselves, the confusing effect Linn (2003) pointed out will not be a big issue.

SimSketch

An established way for students to make sense of the modelling process, is to let students make their own models, let them go through the process themselves (Milrad, 2004). For most modelling programs students would have to learn modelling languages which are often complex (Bollen & van Joolingen, 2013). SimSketch is a tool which makes it possible for learners to build their own models based on their own drawings. These drawings are the objects of the students' model. Students are able to attach behaviour(s) to the object with the help of drag-and-drop tools. These behaviours can only affect the object to which it is connected, or it can be related to other objects. FOLLOW or CIRCLE are two example of these interacting behaviours, whereas ROTATE is an object's independent behaviour. Drawing-based modelling has shown to be "a feasible approach to teaching model-based learning, one that is within the reach of even young children" (van Joolingen et al., 2015, p. 8). A full description of SimSketch is given by Bollen and van Joolingen (2013).

Since students do not have to learn the modelling language when working with SimSketch, this tool is a lot easier to use and a lot faster to learn than other modelling tools. Modelling languages are hard to learn for some students, so by circumventing the need for a modelling language, the complexity of the modelling process is reduced. This enlarges the accessibility of the software, reduces student drop outs and saves learning time. The software has already been considered useful for the learning task in a study of van Joolingen et al. (2015) who concluded the understanding of children about the solar system to be increased when they modelled their own theories. On average, the children in the study of van Joolingen et al. (2015) considered the use of SimSketch to be useful for the learning task.

The advantage of SimSketch, when compared with other existing simulations, is that SimSketch gives you better insight into the reasoning process of the student. In simulations at best students are able to change some parameters and watch what happens, which gives the

teacher almost no insight. In SimSketch students have to design their own model, based on their own knowledge, which shows the teacher their possible misconceptions. They can run the model and see whether the results match their knowledge of reality.

This study will further investigate the role SimSketch could play in teaching diffusion and osmosis to a 4 vwo student.

Diffusion and osmosis

Diffusion and osmosis are key concepts to understand many important life processes. Such processes are often hard to comprehend for most students. Diffusion is the passive and undirected dispersion of molecules, which makes it the primary method of short distance transport in cells and cellular systems in all organisms. Osmosis is the diffusion of free water molecules through a membrane. Water molecules form water bridges with the substances dissolved in it, due to these bindings the molecules become too big to get through the membrane by diffusion. Therefore, only the free water molecules can divide equally over both sides of the membrane. This makes osmosis key in understanding water uptake by plants, transport in living organisms, turgor pressure in plants, water balance in aquatic creatures, and transport in living organisms (Friedler, Amir, & Tamir, 1987). Diffusion and osmosis are chemical processes at the cell and molecular level. Visualising and thinking at this level might be one of the things that make these subjects so difficult to understand for students (Sanger, Brecheisen, & Hynek, 2001). Odom (1995) did a study to determine the major misconceptions students have about diffusion and osmosis. According to this study students have major misconceptions in six of the seven conceptual areas covered by its test; the particulate and random nature of matter, concentration and tonicity (the relative concentration of particles on either side of a semi-permeable membrane), the influences of life forces on diffusion and osmosis, the process of diffusion, and the process of osmosis (see Appendix 1). From all of the misconceptions in these conceptual areas (Appendix 1), three were selected to

intertwine in the assignment. From the particulate and random nature of matter, misconception 1a was processed. This misconception states students to believe particles to stop moving when the osmotic value is equal on both sides of the membrane. This is not true, the particles never stop moving, they will always continue to move from one side of the membrane to the other and back. However, since all the particles keep doing this, this is not visible in a change of the water level. The second misconception, is misconception 1b from the category process of diffusion, which states students to believe osmosis to be the process responsible for the dispersion of a blue dye in a clear water container. Since the process of osmosis needs a membrane, this cannot be true. The third processed misconception is in the process of osmosis category. Misconception 1b states that due to the movement of water from the low to the high concentration, in a u-tube with a semi-permeable membrane, the water level will be higher on the side of the u-tube that contains dye and water, compared to the other side of the u-tube that contains only water. As described before, the movement of water has no direction, which makes it impossible for this process to happen "because water moves from low to high concentration" (Odom, 1995, p. 4).

Two other misconceptions were obtained from the *Kennisbank Misconcepten* set up by the Ruud de Moor Centrum at the Open University at Heerlen (OU, 2017). The first misconception obtained from the *Kennisbank Misconcepten* states students to mix up the characteristics of the cell wall and the cell membrane and that they find it hard to visualise a membrane as a selective membrane since this is not a familiar concept to them. The major difference in the characteristics of the cell wall and the cell membrane are their permeability and rigidity. The cell wall is completely permeable to ordinary macromolecules and can be seen as a sieve with large gaps, whereas the cell membrane is much less permeable and selects the in and outgoing molecules, more like your skin. Further, the cell wall is designed to provide strength and rigidity to the cell, it determines the cell shape and offers protection,

whereas the cell membrane is designed to separate the particles on the inside from the particles on the outside of the cell and is flexible. The second misconception states students to believe that the differences in the concentration of dissolved particles are responsible for osmosis. Although, as explained before, it is instead, the concentration of the free water molecules that create the direction of osmosis.

Odom (1995) concludes diffusion and osmosis should be instructed by specially designed approaches which include instructional strategies that allow students concrete interaction with diffusion and osmosis concepts, but to get a better view of the students' reasoning, research must be done. In this study, those concrete interactions with diffusion and osmosis are provided by SimSketch and the assignment designed for this study.

The importance of models, the promising results of SimSketch so far and the difficulty students have with the concepts of diffusion and osmosis lead to the following research question: What is the effect of the use of drawing-based modelling on the reasoning process when learning about diffusion and osmosis?

Method

(Re)designing SimSketch

As mentioned before, for his study we used SimSketch to model the process of diffusion and osmosis. Before SimSketch could be used to model these processes, some new elements of the software had to be developed. This designing part has been done in consultation with dr. F.A.J. Leenaars. 5 situations are created, every situation a bit more complex than the previous (Figure 1, C - G).

Since the processes diffusion and osmosis are quite complex, some considerations had to be made while creating the settings in SimSketch. The 2D/3D view for instance; at a 2D

screen we want to display a 3D situation, which could be done by pre-programming the drawings to move over each other. However, when all the molecules the student draws are moving over, and therefore not colliding each other, this would not be realistic. Eventually, a 2.5D structure was chosen in which all the molecules are automatically divided over a certain number of layers in which the drawn molecules in the same layer can collide, but the molecules in different layers cannot.

Apart from drawing and modelling the molecules, the students also have to set the effect of the molecules on the water level (blue straight line in Figure 1, D and E) and the membrane (straight red line(s) in Figure 1, F and G). For most students, this will be new since assignments in the schoolbooks and simulations do not ask about those properties. To build SimSketch as basic as possible, we decided to make even these parts of the program adjustable. It is not possible to adjust the membrane in Figure 1E since this membrane is placed in a fixed experimental setup.

The movability of the membranes in the plant cell and the blood cell (Figure 1, F and G resp.) gave rise to another issue that needed a specific treatment. At the membranes of those cells, trans-membrane protein molecules are located. Those membrane proteins enable big molecules, such as glucose, to move through the cell membrane in a passive or active manner. Regrettably, the moving property of the membrane made it technically too complicated to add the trans-membrane protein molecules, which is why we chose not to implement the membrane protein feature.

Assignment

The assignment was created to achieve two goals. The first goal was to guide the participant through the different situations created in SimSketch. While doing so, the second goal was to address the earlier mentioned misconceptions the student might have. In total 5 misconceptions were obtained; 3 from Odom (1995) and 2 from the *Kennisbank*

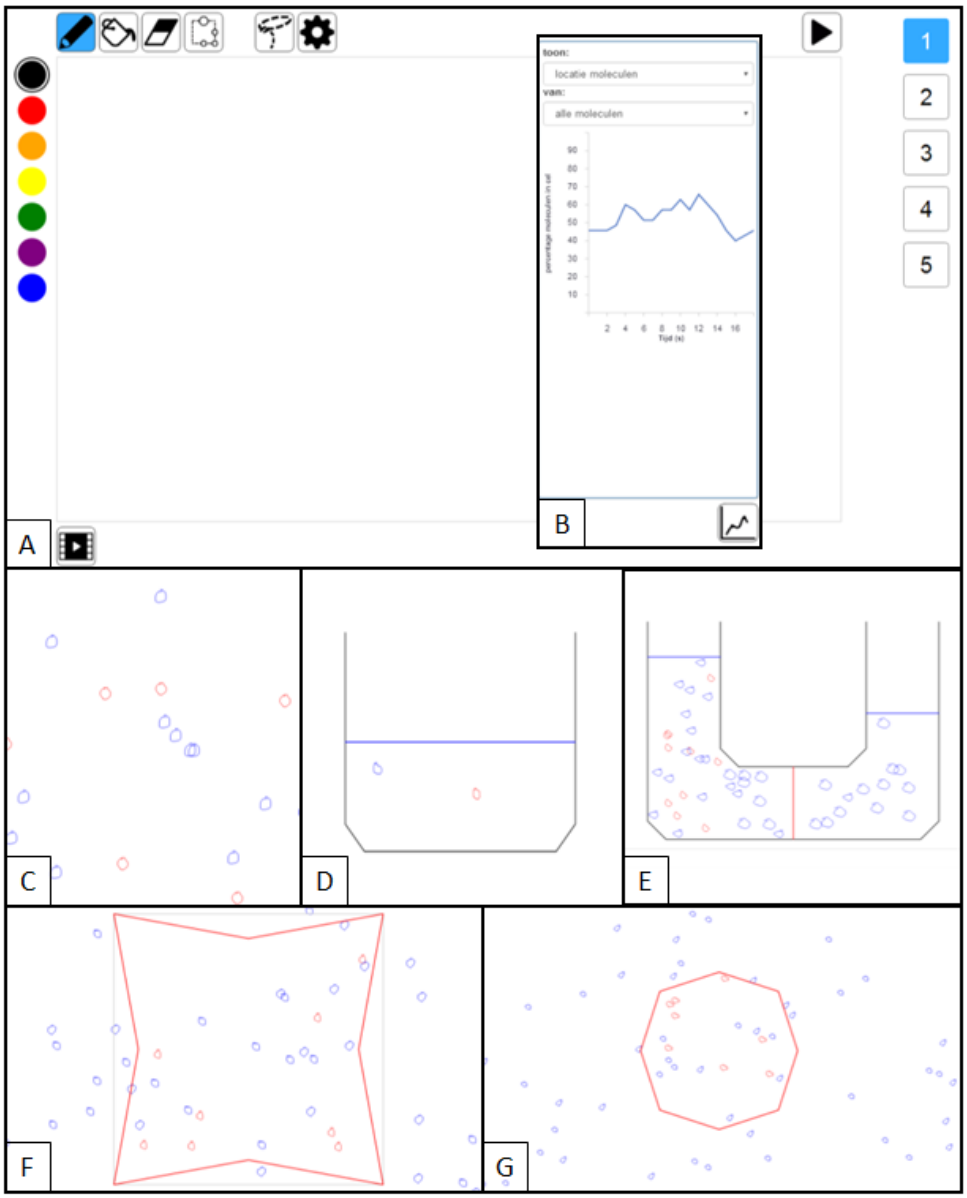

Figure 1. The different views of SimSketch as a tool for modelling diffusion and osmosis. A) The home screen of SimSketch where the modelling takes place. In the left bottom corner, the movie button is visible, the right side displays the different situation-buttons. B) The graph that could be used to analyse the modelled situation. In the bottom right, the button to activate the graph is visible. C) Situation 1; the modelled process of diffusion. D) Situation 2; the modelled process of diffusion in a cup, with an adjustable water level (blue line). E) Situation 3; the modelled process of osmosis with a semi-permeable membrane (red line). F) Situation 4; the modelled process of osmosis in a plant cell with an adjustable cell membrane (red line) and a fixed cell wall (grey line). G) Situation 5; the modelled process of osmosis in a blood cell with an adjustable cell membrane (red line), but without the cell wall.

Misconcepten (OU, 2017). For each misconception, a question or approach was prepared. The first selected misconception discovered by Odom (1995) was about the particles that do not stop moving when the two sides of the membrane have an equal osmotic value. During the assignment, students observed the always continuing movement of the particles, which was

expected to reduce the amount of students who believe the particles to stop moving. The second misconception from Odom (1995) was treated by telling and showing the students the necessity of a membrane in the process of osmosis. The last selected misconception from Odom (1995), was about the random movement of water molecules, which will be visible for the students during the assignment. The first misconception from the *Kennisbank Misconcepten* (OU, 2017) was about the mix up of characteristics of the cell wall and the cell membrane and students difficulty visualising a membrane as a selective membrane. The differences between the cell wall and the cell membrane will be dealt with since the student have to set the characteristics of those themselves. The visualisation of the membrane in SimSketch is, just like in most images, a line that does not suggest more or less selectiveness than the cell wall. Although, since the differences in permeability of the cell wall and the cell membrane will be discussed, the visualisation of the students can be adapted. The second misconception from the *Kennisbank Misconcepten* (OU, 2017) was about the process of osmosis which happens due to dispersion of the free water molecules instead of due to differences in the concentration of the dissolved particles. Questions 9 and 10 are designed especially to cope with this misconception. Here, the student is asked to apply a binding process between the water and the glucose molecules they modelled, the dispersion of the free water molecules will now be visible, and the student is asked to compare the results of this new situation with the previous situation.

The assignment was also designed with open questions which challenge the student to engage a reasoning process, connect their findings to the real world and enlarge their knowledge.

Participants

The five participants in this study were students of 15-16 years old who are in class 4 vwo of high school ‘Lyceum Oudehoven’. They all follow the same biology course, so they all got

the same explanation of the subject. The selection of the participants was done by a different teacher for every hour. Each teacher selected the student they thought was best capable of missing his class. Only the selected student was asked to participate. In case the selected student did not feel comfortable missing its class, the second choice of the teacher was asked to participate. There was no situation in which neither of those two selected students accepted to collaborate in the study.

Procedure

This study took place at Lyceum Oudehoven in Gorinchem. In the educational media centre of this school one computer was reserved for this research all day. During the day, the students were picked up one at the time, therefore, each student had 40 minutes to go through the assignment as far as possible till it was time to pick up the next student. These 40 minutes were recorded in an interview setting to minimise the time lost by writing and optimise the recording of the reasoning mechanisms of the student.

During the interview, an interview guideline was used (Appendix 2). The students were first told what would be happening in the next 40 minutes and their grades were asked; their grade received for the test about the chapter with diffusion and osmosis as well as their average grade for biology last year. Then they were informed about the possibilities of the SimSketch program by handing over the ‘Explanation of SimSketch’ (Appendix 3). Approximately at the same time, the assignment was handed over, and the student was told to think out loud. During the interview, the researcher was present to help the students when necessary. The students have not been assisted in their model-building process, but some help was offered when students had trouble with the program or the assignment.

Depending on the efficacy of the student, the researcher had to stop the student from working on the assignment and continued the interview with models as a head subject, or ended the interview and handed over the ‘Questions of comprehension’. For the interview

about models, a time span of 10 minutes was reserved, and for the ‘Questions of comprehension’ this was between 5 and 10 minutes.

Questionnaire

The questionnaire contains three kinds of questions: Motivational questions, model-understanding questions and questions of comprehension.

Opinion about SimSketch. With these questions, the participants’ motivation, view and the advantages and disadvantages of the program SimSketch, are questioned. There are three main questions, the other questions are mostly for clarification. Those three main questions are; ‘what do you think about SimSketch as a program?’, ‘did SimSketch help you to get a better understanding of the processes diffusion and osmosis?’ and ‘would you like to use SimSketch more often?’.

Model-understanding questions. To examine how well the students are able to understand the model and its use in science, some open questions are composed. These questions are based on the theoretical framework constructed by Upmeier zu Belzen and Krüger (2010) and revised by Grünkorn, Upmeier zu Belzen and Krüger (2014) (see Appendix 4). They designed five aspects of model-understanding; *Nature of models, Multiple models, Purpose of models, Testing models and Changing models*. For each aspect, they formulated three or four levels of complexity. The open-ended item format was chosen since this gives the students the possibility to formulate an answer by themselves without being forced to pick one of the generated response options (Rost, 2014).

Questions of comprehension. Students’ understanding of the concepts diffusion and osmosis will be tested with multiple-choice and open questions. These questions are designed to evaluate the students understanding of the processes after the assignment is done. With the given answers, the expected conception of the students was reviewed. Some questions ask for knowledge that has not been addressed during the assignment. Students must use their

knowledge, imaginativeness and logic thinking to get these right. The answers to some other questions can give a clue about the misconceptions the students have. Three of the mentioned misconceptions are questioned in this evaluation; misconception one, about the stopped movement of the particles when the osmotic value on both sides of the membrane is equal, misconception two, about the necessity of a membrane in the process of osmosis and misconception four, which stated students to believe only the process of diffusion is transporting particles in and out of the cell. For misconception four a second question is added, asking which cell layer is responsible for the particle selection, which was stated by OU (2017) to be mixed up often by the students.

Data analysis

Interview. After the interviews with the students are recorded, they were coded in five categories (see Table 1); *Understanding of SimSketch*, *Prior knowledge activation*, *Reasoning*, *Newly gained knowledge* and *Learning due to SimSketch*. Also, the answers to the *Opinion about SimSketch* and the *Model*-understanding questions are coded.

Understanding of SimSketch is a category designed to gather all the quotes that display how the students get along with SimSketch. All the questions they have about how SimSketch works and all the extra instruction they need to use SimSketch properly are coded within this heading.

All the quotes eventually coded as *Prior knowledge activation* are about knowledge the student already possesses. During the interview, there is a certain amount of questions asking for terms or situations the student should already be familiar with, in those cases the answer is coded as Prior knowledge activation. When the student is not completely correct or experiences a tip-of-the-tongue moment, it was allowed to correct or help out a bit. As long as it is clear the student did already know about this, it will be coded as Prior knowledge activation.

Reasoning is about the quotes in which it gets clear the student is in a reasoning process. This could take place for instance after the student receives new information or is asked to explain what is - or predict what will be - happening. During the process, old as well as new information could be used.

The category of *Newly gained knowledge* contains all the quotes referring to new knowledge or knowledge that has decayed over time and therefore looks like new knowledge.

Learning due to SimSketch is the category in which all the quotes in which it gets clear the student uses SimSketch to get to fresh insights were assembled. If there is a situation in which the student is gaining new knowledge while using the image of SimSketch, this is coded as learning due to SimSketch instead of gaining new knowledge.

The categories *Opinion about SimSketch* and *Models* have been questioned apart from the assignment and are therefore mostly located at the end of the interview and by that matter are clearly distinguished.

Questionnaire. This study contains three questionnaires. These questionnaires all require another method for the analysis.

Opinion about SimSketch. *As with all the spoken texts, the answers at the questions of*

Table 1. The categories created for analysing the students' interviews and their descriptions.

Name	Description
Understanding of SimSketch	All the lines referring to how SimSketch works.
Prior knowledge activation	All the lines referring to knowledge the student does already possess. I am permitted to help or correct a bit to activate this prior knowledge.
Reasoning	All the lines referring to a student its reasoning process.
Newly gained knowledge	All the lines referring to new knowledge or has decayed over time and therefore looks like new knowledge.
Learning due to SimSketch	All the lines referring to the use of SimSketch by students to get to fresh insights.
Opinion about SimSketch	All the lines referring to what the student thinks about SimSketch.
Models	All the lines referring to the knowledge students have about models.

opinion were recorded. However, contrary to all the other data categories there was no specific categorisation-method used for these answers. The answers of the students were compared with each other, bundled if possible and sorted by relevance.

Model-understanding questions. After the assignment with SimSketch, the students would be able to reach a certain level of understanding for the different categories, see Appendix 4. For all five categories of the model, three or four levels of complexity are generated by Grünkorn, Upmeier zu Belzen and Krüger (2014). The level at which each student is reasoning, will be determined for each aspect and displayed in a table. Using these results, a judgement could be made about the student's ability to place a model in the real world.

Nature of models is about the comparability of a model with the original. In the assignment, there are questions which help the student to think of models as a hypothetical representation of the reality, instead of a copy, by helping the student to realise the things they see on the computer screen do partly, but not completely match what is happening in the real world.

The *Purpose of models* is in the assignment every time the student is asked to which degree the model is showing the facts correctly. The assignment did not attempt to enlarge the students' awareness about the fact that models are used to examine ideas until they reach question 9 and 10 in which the students compares two interaction possibilities for molecules. This assignment helps the student to realise a model could be used to identify and explain relationships, instead of just showing the facts.

Testing models is all over the assignment since the student is asked for things they think are not correctly displayed in the model a number of times and are so comparing and matching the model with the original. Also, every time before a student runs a new situation, they are asked to phrase a hypothesis, which gives them the chance to compare their hypothesis with the model.

During the whole assignment, the students work on optimising the model's representation of the reality, which matches the requirements for the *Changing models* category.

Since the assignment was not designed to change the way a student thinks about models, there was nothing in the assignment referring to *Multiple models,* which should be kept in mind while evaluating the results.

Questions of comprehension. Since these questions are used for evaluating the students' expected conception of the diffusion and osmosis processes, the given answers on these question are compared to the quotes from during the interview. These questions will that way make clear whether a student adopted the new knowledge, or did not.

Results

From the coded interviews, we gained results in all the different coded categories. For each category, the differences and similarities in the quotes of the various students are discussed. But first, some differences and similarities between the students will be defined.

Participants

Each student was asked what their grade was for their last test about the chapter containing the subjects' diffusion and osmosis and their average grade of last year. These results, visible

Table 2. Displayed are all the students with their grade for the test about last chapter (including the subjects diffusion and osmosis), their last year's grade and their reached situation during the assignment.

Student	Grade test	Grade last year	Reached situation
1	4	8	Up to and including the plant cell (situation 4)
2	6	6	Up to and including the u-tube (situation 3) + 9 & 10
3	9.5	9	Up to and including the u-tube (situation 3) + 9, 10 & 11
4	5.9	7	Up to and including the plant cell (situation 4)
5	6	8	Up to and including the u-tube (situation 3) + 9 & 10

in Table 2, are scaled on a one to ten scale, in which a score higher than six is a passing grade. The last column in Table 2 shows the latest situation of the assignment each student reached. Since some students walked through the assignment quicker than others, all students completed situation 3 with the u-tube, but just two students completed situation 4 (although all students did two of the questions from this situation). Due to the lack of time, none of the students started situation 5 with the blood cell.

During the assignment, some students are more busy with the gaining of new knowledge than others according to the things they say, as shown in Figure . Student 5, for example, is more busy gaining new knowledge, while student 1 and 3 are activating prior knowledge

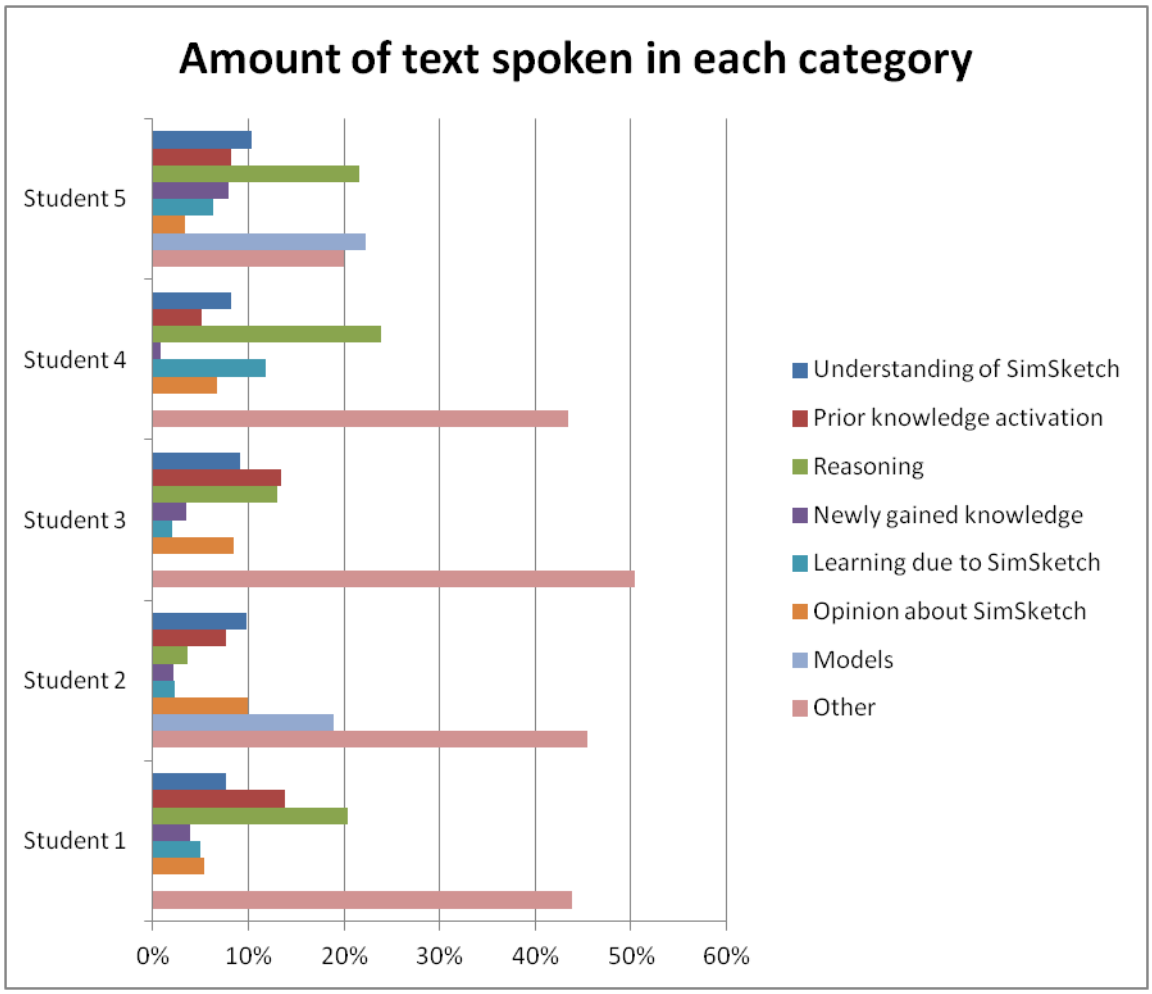

Figure 2. All the interviews are coded into seven main categories, each category contains a percentage of the total amount of text. The 'other' category contains all the quotes that were not coded in any of the seven main categories.

more than gaining new knowledge. Student 4, on the other hand, seems to be learning quite something due to SimSketch, but does not seems to gain a lot of new knowledge independent of SimSketch.

The students also differ in their way of putting up with SimSketch, the newly provided information and the assignment. During the task, students 2 and 3, for instance, are a bit more hesitant while working with SimSketch and going through the assignment. As so, those students needed more guidance to move on to the next question or action than the other students did. Unless this is what was experienced during the assignment, student 2 reached up to the same question as student 5 did (Table 2). This could be explained by the fact that student 5 used more time to think out loud while reasoning and gaining new knowledge, as shown in Figure 2.

Interview

Understanding of SimSketch. Concluding from Figure 2, all students have about the same amount of texts in the 'understanding of SimSketch' category. They also do not differ a lot in the content of those quotes. How to place the property-symbol at the molecule, for instance, this drag and drop system has been explained to all the students. How big you should draw your molecules, is another example of frequently coded quotes. These are examples of information that has not been included in the sheet with the 'Explanation of SimSketch' (see Appendix 3), which makes the frequent existence of those explanations accountable. On the other hand, student 1, 2 and 3 asked where they could find the possibility to adjust the amount or some other property of the molecule, while the answers to those questions were displayed on the sheet with the explanation of SimSketch. Since we had a short amount of time for each student, there was no hesitation answering these type of questions, resulting in an often mostly vocally given explanation of SimSketch.

Despite, students 2 and 3 were a bit more hesitant while working with SimSketch, all the

students seem to quite easily understand how the program works.

Prior knowledge activation. The sentences coded for this category allow us to make conclusions whether the students still know the basic principles of diffusion and osmosis from their biology lessons. Some knowledge was present by all the students, some other subjects were only presented by one or two of the students. All the students did, however, recognise the situations presented to them and were able to create hypotheses based on their basic knowledge.

The effect of heating to speed up the molecules was the only subject in which all the students were completely correct. The properties of a semi-permeable membrane have also been broad up by all the students, but not all the students remembered which kind of molecule could and could not go through a semi-permeable membrane. Students 4 and 5 remembered some deeper knowledge, telling us about the necessity of cell membrane proteins to guide glucose in and out of the cell. Student 5 (S5), however, mixed-up the properties of the cell wall and the membrane, talking at the interviewer (I) about needing proteins to go through the cell wall instead of the cell membrane.

S5 Can happen with the help of proteins, but not with something of itself
I Do you mean though the membrane or the wall?
S5 Well, it can't just pass the membrane since it is too big, but for the cell wall you need proteins to get it through. [12:25]

The term turgor pressure was one of the terms presented for the first time in the assignment at situation 4, wherefore student 2, 3 and 5 were not asked to reproduce this term, since they did not make it up to situation 4. Student 1 and 4 were both able to identify the turgor pressure in the plant cell.

A remarkable absence was noticed for the term osmotic value. This is one of the key terms of osmosis and was for that matter expected to be mentioned by all the students during the interview, but in fact only student 1 described the definition of the term. The term itself was

not mentioned by any student, they mostly spoke about the concentration of dissolved substances instead of osmotic value.

Reasoning. The first question in which it was necessary for the students to start a reasoning process was about the possibility for some molecules to just pass, while some others bump into each other. Eventually, all of the students came to the conclusion that this must be due to the symbolising of a 3D world, but two of the five students needed a bit of help to realise this.

Another subject all students reasoned about, was the setting for their water level in situation three. The possibilities were to let the level depend on the amount of water and glucose or just one of those two. Obviously, both molecules have a certain volume, which makes them both responsible for a higher water level. However, not all students came to this insight; student 1 believed only the water molecules were responsible till she was asked about the volume of glucose, and student 3 (S3) had an interesting reasoning in which both sides of the u-tube in situation three had a different setting for the water level;

I *Yes, this is about the water level, how high it should be.*
S3 *Yes, well this side doesn't contain glucose, so then it should be only water responsible.*
I *Okay, and the other side?*
S3 *Both, because they are both in there.* [15:48]

A remarkable reasoning statement was done by student 3 and 4 who both argued the diffusion process of situation 1 (in the air) to go faster than the diffusion process of the movie added to situation 1 (in water). There is some logic in this since gas molecules move faster than water molecules, diffusion will also be faster. But the movie was about making tea which is normally done with boiling hot water, which means the molecules in this water will also move quite fast. Student 3 did argue the dispersion to happen faster in the air since it is a gas, but she did not continue her reasoning after the hotness of the water was pointed out. With

student 4 it was more some kind of feeling she had that made her conclude the dispersion will happen faster in the air since she could not come up with an argument to conclude this. Despite the lack of argumentation, it was interesting both students came up with the same statement.

Newly gained knowledge. The most remarkable statement coded in this category, came from student 1 saying she had never heard her teacher say something about the necessity of a membrane in the process of osmosis and not in the process of diffusion. Since none of the other students said anything like this, despite the fact they all have the same teacher, she probably missed this information or understood it wrongly. Student 1 also did not know the difference in permeability between the cell wall and the cell membrane. This was explained to her by visualizing the cell wall as a big holed net, used to strengthen the cell, while the cell membrane is more like a sieve with small holes that only let small molecules through. Most of the other students did not seem to have a problem with this difference, except for student 5 who was the only one showing she still knew there was something about a protein to guide the glucose molecule in and out the cell. She did, however, talk about these proteins to be placed on the cell wall instead of on the membrane, resulting in the new information that those proteins are located at the membrane and the cell wall looks more like a colander with big holes in it.

Learning due to SimSketch. Due to the visibility of molecules in SimSketch, the students came to some insights. For instance, the random movement of water molecules with the resulting variance in the water level and shrinking and growing of the cell membrane. Especially when your settings are that there is no binding between the glucose and the water molecules, these fluctuations are quite substantial, like student 1 (S1) describes;

> *S1 No, the uhm membrane. It expands a bit and then it shrinks a bit because water molecules are getting in more at a certain time and less or out a second later.*
> [21:40]

Binding of glucose and water. Since there are quite a lot of quotes assembled about the binding of glucose and water, which do not all fit in the same coding-category, they were assembled here. This binding process has a lot to do with the previously described fifth misconception about the concentration of the free water molecules to be responsible for the direction of osmosis.

While programming the binding of the water molecules at the glucose molecules, student 3 started reasoning about its effect on the movements of those bonded molecules. Student 2 started questioning about the things she saw after pushing the play button (new knowledge). Both processes resulted in the conclusion student 2 (S2) gave after playing the model;

S2 *O than a lot of water thingies get stuck on it. Now it* [the water molecules shown in the graph] *is all high.*
I *And how is that possible?*
S2 *Because the water molecules cannot go back, because the glucose cannot go through the membrane and it is stuck on the glucose.* [20:01]

After concluding that this binding process kept some of the water molecules stuck on the glucose molecules inside the cell, the dispersal of the other water molecules is examined. Students 4 (S4) and 5 used the graph in SimSketch, which displayed the number of water molecules on the outside of the cell, to come up with an explanation of this process;

S4 *Than it is very low, than it is much lower. So there are more water molecules in the cell if it has bonded with glucose.* [23:14]

Finally, the students were asked to conclude which of the tested situations would be more realistic, the one in which the water and the glucose molecules did bind with each other or the situation in which they did not. All students used SimSketch, reasoning or both to conclude the binding process to result in more realistic results.

I *So, is this more or less realistic than what you saw before?*
S3 *Uhmm I think it is more realistic*

I *More realistic? Why do you think so?*
S3 *Because it* [the water level] *already gets a bit higher on that side* [pointing to the side of the graph with the high osmotic value] [24:05]

Only student 2 questioned the reality. Although she thought the Graph she had seen with the binding water and glucose molecules was more realistic, she was not sure for it to be enough information to ground her conclusion on.

Questionnaire

Opinion about SimSketch. The overall opinion of the students about SimSketch turned out to be positive, all students would have liked to use this program while learning about diffusion and osmosis. They thought SimSketch to be an easy to use software, they liked that you have to create all the objects and their features by yourself and argued this to reinforce your understanding. Also, the fact that you are able to see what is happening exactly, is mentioned more than once. The students appreciate seeing the movements of the molecules rather than stationary figures, in which student 4 specifically names the aimlessness of the movement of the molecules as a help to enhance her understanding. Movie clips also have the respected movements in it, but, as student 1 argues, in most movie clips there is more to see than just the molecules and process that you are interested in. These other objects in the movie can be very distractive and confusing. Nevertheless, student 5 did appreciate the movie clips added to the SimSketch program very much.

In addition, student 3 stated SimSketch to be more explicit than the program Coach while creating the model as well as in interpreting the results. According to student 3, Coach has some strange arrows and settings and the results of the model are displayed in vague figures.

Despite all the positive points the students addressed about SimSketch, student 2 answered “no” to the question whether she would like to use SimSketch again. After some more questioning, it became clear she was not willing to use SimSketch for the subject diffusion

and osmosis again because she did already know how those processes work. Had we offered her to use SimSketch while she was still learning about those processes, she would have liked to use SimSketch.

Table 3. For each aspect of the theoretical framework of models four levels of understanding are created by Grünkorn, Upmeier zu Belzen and Krüger (2014) (see Appendix 4). For each student, their reached levels in each category are shown with an example of one of the students' quotes. Sometimes multiple quotes of the same student are scored at the same aspect, this could be at the same or at a different level.

Aspect	Complexity				Example Quotes
	IL	Lvl 1	Lvl 2	Lvl 3	
Nature of models				S2	Y So, everything that happens in this model, or in another model, must it be true? If the model of the flu epidemic, for instance, predicts a lot of flu at a certain location. S2 Then that does not have to be true because if you change something the prediction will not be true anymore. "..." Would you, for instance, remove all people from the given spot, the prediction will not be correct anymore. [29:15]
				S2	
				S5	
		S5			Y What do you think about when we talk about models? S5 Uh at a uh simple reproduction of what really happens. [31:31]
Multiple models			S5		Y Imagine you constructed 6 models of the flu epidemic, can you then somehow tell which model is the best? S5 Yes, it depends on the values you put in Y What do you mean? S5 You can for instance study the number of infections and the number of people that die due to the flu "..." than older people die earlier due to the flu than normal healthy people and if you also distinguish between the death of children, grownups and elderly people than you have an even better report. [33.01]
Purpose of models		S2			Y So, what was the purpose of the model? S2 Uhm it showed an epidemic of the flu. [27:07]
		S5			
Testing models			S2		Y When you have multiple models, and you already have the data of the flu epidemic inserted, how can you then choose which model is the best? Would you be able to pick one? S2 I think you could. They know which one resembles the real epidemic the best, that would be the best model. [28:00]
			S2		
Changing models			S5		Y And when you have multiple models S5 Then you will be finding an even better answer each time, every time it becomes more precise and more correct. [32:49]

Model-understanding. The insight into the student's understanding of models and their use in science was extracted from the classification of the quotes about models (Appendix 4). Due to the short amount of time for each student, only student 2 and student 5 answered the model-understanding questions. The quotes of those students were classified and the results are shown in Table 3.

One of the quotes of student 2 (S2) definitely is about the theoretical framework of models, but did not fit in any of the aspects mentioned above, since these aspects do not consider the different appearances of models. Despite the missing *Model appearances* –category, this quote should be considered to be important since it seems to say only a graph or a table are acknowledged as models to this student;

I *When you think it is hard to understand how something works, is making a model than a good solution for you?*
S2 *Depends on the subject*
I *Why?*
S2 *Well.. some things can't really be displayed in a graph or a table.* [28:30]

Student 5 also gained an interesting quote which did not fit in one of the existing categories. In this quote, she tells models to be more accurate if it contains more characteristics of the original. But she disagrees with the statement of models to be better when they are more enhanced. The more information is put in the model, the more complex it gets and how harder it gets to extract a conclusion. Although, according to student 5, when you understand this complex model well enough you will be able to extract a more accurate conclusion.

Questions of comprehension. For each student, the answers on this test are compared to the quotes and the experience during the assignment. Overall speaking, each student at least reached the expectations. Student 1 (S1) learned two important new things during the assignment, namely the difference in the selecting features of the cell wall and membrane and

the importance of a membrane in the process of diffusion. This newly gained knowledge is correctly applied during the test. However, she gave the wrong answer to the question about the expectation of the effect of a high osmotic value insight a blood cell despite she told us during the assignment what would happen in this case;

> *S1 Uhm, yes because our teacher taught us that it will just that thing fills up till it cannot be more full and that, if it has not got a cell wall, it will explode.* [27:40]

Another question she answered incorrectly was about the conditions that would make the process of diffusion faster; higher temperature, bigger point of contact and/or bigger concentration-differences. Only the effect of higher temperatures is discussed during the assignment, which was also the only change that would make a difference according to her answer, while actually all of those changes would make the diffusion process go faster. The third question in which she was mistaken was about what has to happen to stop the process of osmosis. After the assignment, she was expected to be able to conclude there is nothing that will stop the process of osmosis, since the molecules will never stay in place. But she answered the process to stop if the osmotic value is equal at both sides of the membrane.

Student 2 made fewer mistakes on questions discussed during the assignment. She missed the fact that enlargement of the point of contact will make the process of diffusion faster, but she did get the effect of the bigger concentration-differences. She forgot to mention the fact of osmosis to be only about the migration of water molecules and no other molecules. And she answered diffusion does not take part in the process of molecule-migrating in and out of the cell, which it does.

Student 3 had a 100% score on the test, but we cannot conclude this to be all due to the assignment. During the assignment, student 3 was holding back a bit, with a relative lot of doubt about what she had to do and how she should do the assignment. These results on the test display these doubts had nothing to do with a lack of knowledge.

Student 4, just like student 1, answered the process of osmosis to stop if the osmotic value was equal at both sides of the membrane and she missed the effect of the enlargement of the point of contact, just like student 2.

As we already discussed, student 5 was a bit confused about the membrane proteins and the location of the selection of the molecules. In the test it became clear she still did not get this part jet, since she answered the selection of molecules to happen in the cell wall instead of the membrane. She also forgot to mention the necessity of a membrane in the process of osmosis. These two questions should have been answered correctly after the assignment. She also had a bit of trouble with two questions about the blood and the plant cell, discussed in the not reached situation 4 and 5. In her answer to these questions she concluded the blood cell to shrink if its inner osmotic value was high in comparison to its surroundings, just like student 1 did. Except, contrary to student 1, student 5 concluded the same thing to happen with a plant cell in the same situation which suggests a more structural misunderstanding of the process or the test-question.

Conclusion and discussion

Taken all of these results together, a conclusion could be made on the research question into the effect of the use of drawing-based modelling on the reasoning process when learning about diffusion and osmosis? According to the presented results, two effects became clear. First, during the assignment, the students were corrected by the effect of their own settings, since the results of their settings are visible when the model is played. With the help of their knowledge of the subject and their hypothesis made before playing the model, the student must be able to judge the correctness of the model to some extent. When a student observes its model to be incorrect, they can go back to the modelling stage to rectify the error. Students

are in this way correcting their own mistakes and misconceptions. This does regrettably not apply for all the mistakes since the students do not always know what to expect.

Second, the errors the students make are more easily to discover for the teacher which makes the possible misconceptions students have more visible and therefore, better to deal with. Since students can only model the features they know about, it becomes clear what those students do and do not know about the subject. This way, the student's knowledge and misconceptions appear. It is then up to the teacher to unravel these misconceptions and to enhance the lacks of knowledge of the students.

Further, conclusions can be made on the aspects mentioned in the theoretical framework; models, SimSketch and Diffusion and osmosis.

Models

Leading from the model-understanding questions a judgement could be made about the student's ability to relate a model to the real world. The students seem to understand the feature of a model as a representation of the real world, instead of a replica. This means the students can use a model to understand the complicated things in life without believing it to be exactly like the model. There is, however, nothing from which we can conclude the assignment helped to construct the theoretical framework of models of the students. This is also visible in the fact that neither of them spoke about the model as a tool to test a hypothesis (*Testing models*), while during the assignment they had to make a hypothesis before they were allowed to push the play-button. Or in the fact that they did not mention a model to be useful in identifying relationships (*Purpose of models*), while during the assignment they modelled the water to bind with the glucose molecules in order to identify their relationship. It could be that the student did indeed not make this link with the assignment when being asked

about models, but we must also consider the interviewer and her lack of time to be the reason of not completely find out all the knowledge the students has about models.

Contrary to the lack of knowledge in the *Testing models* and *Purpose of models* categories, the students mentioned a feature of a model which was suggested by Rothenberg (1989) but was not included in the theoretical framework of Grünkorn, Upmeier zu Belzen and Krüger (2014), namely the *Model appearances*. The different forms of representation - and so the different appearances of models and the students' knowledge about this - has not been questioned, but does seem to be an interesting aspect since one of the students stated that it will not be possible to make a model for everything. According to this student, this is not possible since it is not possible for everything to be displayed in a graph or table. Clearly, this student does not think about all the other possible appearances of a model, such as a mathematical formula or a scale model.

SimSketch

To start with the remarks of the students, we could conclude SimSketch to be helpful in visualising the process of diffusion and osmosis in which the moving molecules make SimSketch better than an image and the lack of extra objects the students do not understand - and often do not even have to understand - make it better than a movie clip. Furthermore, the modelling process and interpreting the results is a lot easier when working with SimSketch than it is when working with the program Coach, which the students used before, since the modelling process as well as interpreting the results is easier in SimSketch according to the students. The students also mentioned SimSketch to be easily understandable, however it should be noted that most students in this study got a mainly direct instruction due to the lack of time. This results in two side notes: no conclusion could be made about the accurateness and completeness of the 'Explanation of SimSketch'(Appendix 3) since the students did not or not much use it. And two; we cannot conclude this diffusion and osmosis version of

SimSketch to be understandable for the students when there is no teacher around to help. However, we can predict it to be understandable for a student on its own given the recorded problems during the interview.

Earlier the technical ability to insert membrane proteins has been discussed. After doing the interviews with the students, the necessity of this factor has been enhanced since student 4 as well as student 5 mentioned these proteins to be part of the process. Despite the technical difficulty, we could have inserted some information and/or questions about this in the assignment. Improving the assignment in this way would be an advice for further research.

Diffusion and osmosis

According to the spoken and visible actions of the students, we can conclude most basic knowledge to be still known by the students. There were some difficulties with the permeability of the cell wall and membrane, which was also mentioned as the fourth misconception. During the assignment, some students mixed up of the characteristics of the cell membrane and cell, as predicted by OU (2017). However, after explaining the differences, most students did not have any difficulty reactivating or changing this knowledge, since only one student still mixed these characteristics up during the questions of comprehension.

A remarkable missing term was the osmotic value. As argued, this is an important term not mentioned by the students which is another aspect that should be implanted in the questions of the assignment. In this case, asking about it in the assignment will probably be enough since the students did seem to understand what the interviewer was talking about when "osmotic value" was mentioned.

The random movement of water molecules, which was mentioned as misconception three, became clear to the students during the assignment. While working with SimSketch the

students observed the molecules disperse over the available space instead of heading in a certain direction.

All students ended their assignment with the questions about the binding process of water with glucose, which had everything to do with the fifth misconception as mentioned before. These questions revealed the students were able to explain what they saw happening in SimSketch, although not all students were able to explain what the effect of this linkage would be for the cell and the process of osmosis. Despite this, all students were able to explain if and why they thought the new situation was more like the original. They were able to make an assessment about this and formulate arguments for support. During the questions of comprehension all students, except one, answered osmosis to be all about the migration of the water molecules, suggesting the students understand that the dissolved particles instead of the free water molecules are responsible for the direction of diffusion.

The results of the test at the end of the assignment suggest more attention is needed to clarify to the students that the process of osmosis never stops, which was mentioned as misconception number one. The molecules will always continue to move through the solution which includes moving through the membrane. This movement will also continue when a stable situation has been reached, the osmotic value is equal on both sides of the membrane and no fluctuations in the liquid level are visible. Despite all students witnessed the ever-moving molecules in SimSketch, two of the five students answered osmosis to stop when the osmotic value reached an equal situation which is enough to suggest more explicit attention should be paid to this in the assignments of further research. Also the necessity of a membrane in the process of osmosis – misconception two - should be mentioned or questioned more explicit, since one student did not mention this during the test while describing osmosis as accurately as possible.

Recommendations

Advice has already been given about the implementing of the membrane proteins, the osmotic value, the fact that osmosis never stops and the explicit mentioning or questioning of the necessity of a membrane in the process of osmosis in the assignment. Next to these changes in the assignment, research should be done about the timing of this programme in the learning process of diffusion and osmosis. Van Joolingen et al. (2015) concluded that older participants (exact ages not mentioned) see less value in the drawing-based models of the elementary astronomy for learning approach since these students have extensive knowledge about the main subject. In this study, we saw the same with student 2 who answered she would not like to use SimSketch for the subject diffusion and osmosis again because she knew already how those processes work. She would, however, has liked to use SimSketch while she was still in the learning process, just like the other students. On the other hand, there is no use for students to work with the program when they do not understand what is happening due to a lack of knowledge about the processes of diffusion and osmosis. This raises the question at which moment during the learning process SimSketch should be implemented to gain the highest effect.

Furthermore the assignment should be a cooperative learning task, to stimulate students critical thinking and problem solving (Barkley, Major & Cross, 2014). This will have a positive effect on the discussion about the changes that should be made in SimSketch and the answers that should be given. Working in groups will also enlarge the learning effect and the persistency of the students (Johnson & Johnson, 1986). Since the assignment requires a computer, a group of two would be the advice to make sure each student is able to see the computer screen.

To be able to complete the whole assignment at least two lessons should be reserved. The assignment can also be given as homework since the students are able to access SimSketch on every computer with an internet connection.

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Appendix 1. Misconceptions, Odom 1995

Table 3. Percentages of responses by secondary biology students, college nonbiology and biology majors with specific misconceptions detected by the Diffusion and Osmosis Diagnostic Test.

Misconceptions	*Secondary Biology*	*Nonbiology Majors*	*Biology Majors*	*Item*
The Particulate & Random Nature of Matter				
1. Particles move from high to low concentration because:				
a. They tend to move until the two areas are isotonic and then the particles stop moving.	22.4	32.5	33.3	2
b. There are too many particles crowded into one area, therefore they move to an area with more room.	18.9	31.7	26.5	2
2. As the difference in concentration increases between two areas, rate of diffusion:				
a. Increases because the molecules want to spread out.	13.8	27.6	29.1	3
b. Decreases because if the concentration is high enough, the particles will spread less and the rate will be slowed.	19.8	18.7	12.8	3
3. When a drop of dye is placed in a container of clear water the:				
a. Dye molecules continue to move around because if dye molecules stopped, they would settle to the bottom of the container.	26.7	13.0	6.0	6
b. Dye molecules continue to move around because this is a liquid; if it were solid the molecules would stop moving.	3.5	6.5	11.1	6
Concentration & Tonicity				
1. A glucose solution can be made more concentrated by adding more glucose because the more water there is, the more glucose it will take to saturate the solution.	26.7	22.0	20.5	4
2. Side 1 is 10% salt solution and side 2 (15% salt solution).				
a. Side 1 is hypotonic to Side 2 because water moves from high to low concentration.	19.8	15.4	6.0	9
b. Side 1 is hypertonic to Side 2 because the water moves from high to low concentration.	7.8	10.6	3.4	9
The Influence of Life Forces on Diffusion & Osmosis				
1. If a plant cell is killed and placed in a salt solution, diffusion and osmosis will not occur because the cell will stop functioning.	25.0	26.8	22.2	11
The Process of Diffusion				
1. The process responsible for a drop of blue dye becoming evenly distributed throughout a container of clear water is:				
a. Diffusion because the dye separates into small particles and mixes with water.	17.2	18.7	20.5	1
b. Osmosis because there is movement of particles between regions of different concentrations.	11.2	14.6	5.1	1
2. When sugar is added to water, after a very long period of time the sugar will be more concentrated on the bottom of the container because:				
a. There will be more time for settling.	10.3	25.2	7.7	5
b. The sugar is heavier than water and will sink.	26.7	22.0	40.2	5
c. Sugar dissolves poorly or not at all in water.	11.2	8.9	12.8	5
The Process of Osmosis				
1. Two columns of water are separated by a membrane through which only water can pass. Side 1 contains dye and water; Side 2 contains pure water. After two hours, the water level in Side 1:				
a. Will be higher because water will move from the hypertonic to the hypotonic solution.	13.8	22.0	16.2	8
b. Will be higher because water moves from low to high concentration.	18.9	13.0	15.4	8
c. Will be lower because water will move from the hypertonic to hypotonic solution.	12.1	14.6	14.5	8
d. will be the same because water will become isotonic.	1.7	17.1	13.7	8
2. If a freshwater plant cell was placed in a beaker of 25% salt water solution, the central vacuole would decrease in size because salt absorbs the water from the central vacuole.	31.9	35.8	19.7	10

Appendix 2. Interview guidance

text => performed action

"…"=> answer given by the student

We are going to work with the subject diffusion and osmosis and the program SimSketch. I am busy developing this lesson material and I would like your opinion on it. To be able to test the program I designed a number of tasks and questions which will all be on the subject of diffusion and osmosis. Diffusion is about the dispersion of particles through the available air or liquid. And by the process of osmosis, we will investigate what the effect is of the presence of a semi-permeable membrane. Do you know what a semi-permeable membrane is? "…" (if necessary explain). We are going to see whether you are able to model these processes with a little bit of help, to do this we will use the program SimSketch. Let us start with starting up the program.

Give 'Explanation of SimSketch' [see Appendix 3] and start up SimSketch

With SimSketch you are able to model processes by the use of drawings. That might sound complicated, but let us just try. You can just give the answers to the questions out loud, that will save you the time of writing it down.

Give 'Tasks and questions'

Go through the assignment and question the student while finding out the answers to all the questions

Well, you did it! You modeled all the processes. What did you think of the program SimSketch? "…"

Do you have the sense that the tasks helped you in understanding the processes of diffusion and osmosis? "…"

Would you like to work with SimSketch more often? "…"

I have a list here with a few questions, could you answer these for me, please?

Give 'Questions of comprehension'

We are now being busy with models the whole time, are we not? But what do you know about models? What do you think of when thinking about models? "…"

Do you know what models are used for in science? "…"

Is everything shown in and with a model reliable and totally correct? "…" (if necessary; Why?)

How are you able to determine the model to be reliable and correct? "…"

Should a constructed model be tested? "…" (if necessary; Why?)

And if there are multiple models constructed to describe a certain process, is it then possible to test which model is best? "…" (if necessary; How?)

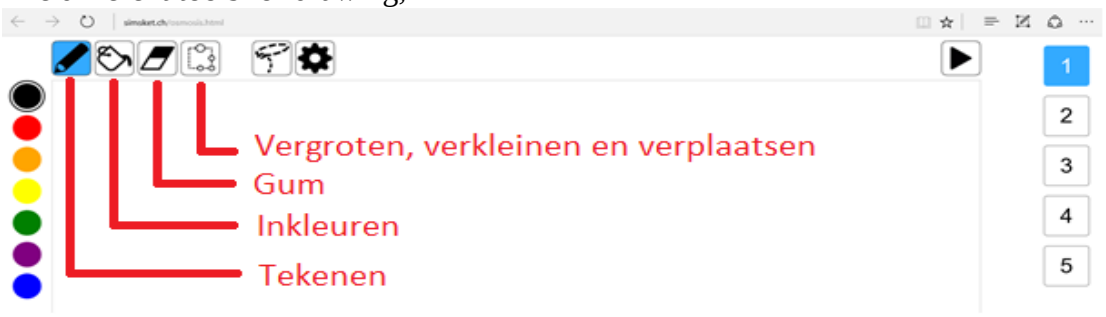
So, what do you think, is it wise to use models when trying to get a better understanding of a complex phenomenon in science? "…"(if necessary; Why?)

Thank you very much, I am a step closer to a beautiful conclusion. And I hope you enjoyed working on this! Have a good day and a nice weekend!

Appendix 3. Explanation of SimSketch

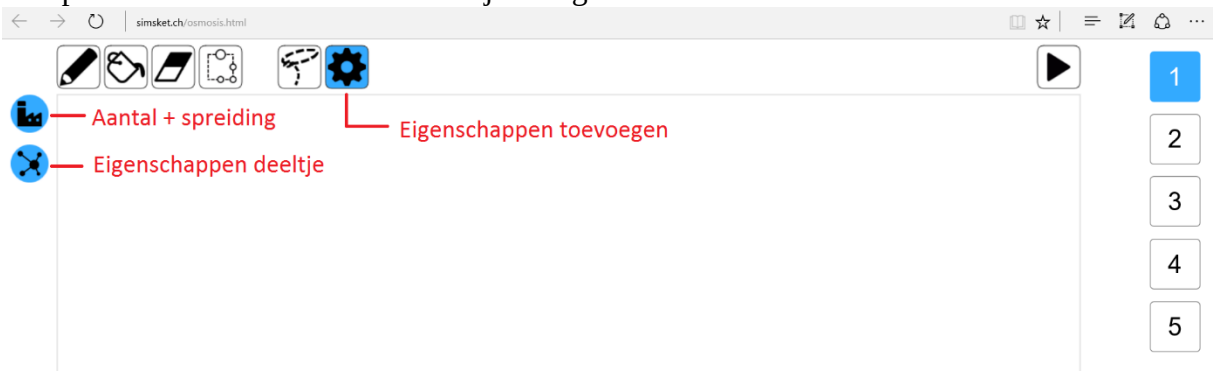
The link to the program SimSketch, that we will be working with;
http://simsketch.science.uu.nl/osmosis.html

The different tools for drawing;



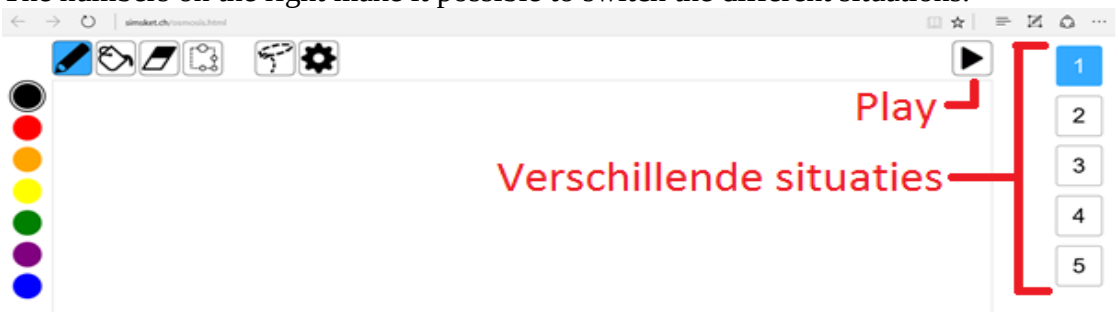
The symbol of the lasso will not be used.

After clicking on the gear sign, characteristics can be added. After clicking on the gear it is also possible to click on the drawn object to give it a name.



To play your model, click on the play-button.

The numbers on the right make it possible to switch the different situations.



Appendix 4. Theoretical framework models

Grünkorn, Upmeier zu Belzen and Krüger (2014), p. 26

	Complexity			
Aspect	**Initial level**	**Level I**	**Level II**	**Level III**
Nature of models	—	Model as copy Model with great similarity Model represents a (non-) subjective conception of the original	Parts of the model are a copy Model as a possible variant Model as focused representation	Model as hypothetical representation
Multiple models	All models are the same Various models of different originals. Only one final and correct model	Different model object properties	Focus on different aspects	Different assumptions Different assumptions with prospects of application
Purpose of models	—	Model for showing the facts	Model to identify relationships Model to explain relationships	Model to examine abstract ideas Model to examine concrete ideas
Testing models	No testing of models	Testing of material Testing of basic requirements	Comparison between original and model Comparison and matching of original and model	Testing hypotheses Testing of hypotheses with research designs
Changing models	No reason for alteration Alteration of how different originals are represented	Alterations to improve the model object Alterations when there are errors in the model object Alterations when basic requirements are not met	Alterations when model does not match the original Alterations due to new findings about the original Alterations due to changes in the original	Alterations due to findings from model experiments