# SCAFFOLDING THE MODELLING PROCESS IN EARLY SCIENCE EDUCATION

*An experimental study on children's modeling performance and learning outcomes*

ABSTRACT- The inclusion of models in the science curriculum shows promise to let students understand science and acquire scientific skills. By using and designing a model children engage in science as if they are scientists themselves. Engaging in modeling differs from the more traditional curricula in that it is characterized by open ended, discovery based learning in which the information is not structured. This makes modeling difficult and can inhibit the learning outcomes. To let more students benefit from modeling research points to the inclusion of fitting scaffold to help students regulate their learning process. However, how scaffolds interact with modeling has not been researched thoroughly. This study researched the influence of scaffolds on the modeling performance and learning outcomes of children (7-16 years old). An total of435 children participated and designed a model in the drawing based modeling tool SimSketch in which scaffolds in the form of required, in-built prompt. Results showed that the children who used the prompt questions to support the right strategy showed higher modeling performance and better understanding of science. Furthermore, it was shown that better modeling performance is related to better model-based reasoning skills. This study concludes by stating that early science education can benefit from the inclusion of models with fitting scaffolds.

*Keywords: Science Education, Modeling, Scaffolds, Prompt Questions, SimSketch, Young Children*

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## 1. Introduction

Science education is changing. The aim of the science curricula shifts from learning conceptual knowledge and studying facts towards a focus on acquiring scientific skills (Richland & Simms, 2015). Students should be able to think critically about scientific issues and by doing so understand the underlying mechanisms, values and assumptions of scientific practices (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002). Through the rise of technology and the fields of computer learning students are now able to learn scientific practices in an authentic way by acting as if they are scientist themselves. Especially the field of designing and using models seems promising in understanding science (Gilbert, 2015) and participating in authentic scientific practices (Louca & Zacharias, 2012). Moreover, model usage has been highlighted by the standards of the K-12 science education (NRC, 2012). A model is "a representation of an idea, process, object, event or a system" (Gilbert & Boulter, 2012, p. Vii) and is seen as a key feature in science (Coll, 2005; Gilbert, 2015). Modeling is in line with inquiry learning and allows students to engage in concrete scientific practices and research topics that would not have been possible without modeling: for instance, studying processes that are too small (cell division) too big (the solar system) or that would take too long (evolution) (Osborne, 2014). Through the use of models these phenomena can become insightful and less abstract and themes can be made workable and easy to understand.

By engaging in modeling the learner has to translate internal ideas into an external representation which has a strong positive influence on reasoning (Löhner, van Joolingen, Savelsbergh, & van Hout-Wolters, 2004). In doing so, mental models become visible and explicit by which the underlying mechanism of a system or phenomena becomes clear (van Joolingen, Bollen, Leenaars, & Gijlers, 2012). When evaluating the model, the model might be adapted and revised which challenges the internal and the external existing model (Van Borkulo, 2009). By creating a hypothesis, running the model, critically evaluate results, adjusting the hypothesis and forming a conclusion students become accustomed to the scientific method in an authentic way (Louca & Zacharias, 2012). The constructed model shows a network of ideas concerning experiences of real world phenomena and functions as a bridge between theory and reality (Gilbert, 2004).

Engaging in modelling differs from the more traditional curricula in that it is characterized by open ended, discovery based learning in which the information is not structured (Devolder, Braak, & Tondeur, 2012). Due to its demanding nature it is especially for young, novice learners unclear what is expected and they are therefore unable to gain from working with models. Research points out the benefits of the inclusion of fitting scaffolds as support in the modeling environment (Sins, Savelberg, & van Joolingen, 2005). However, how the inclusion of scaffolds influences and interacts with modeling activities has not been studied thoroughly (Louca & Zacharias, 2012). Yet, the potential of including scaffolds in the modeling environment is highlighted by many researchers (Louca & Zacharias, 2012; Sins, Savelberg, & van Joolingen, 2005; Azevedo, Cromley, Winters, Moos, & Green, 2005) and has proved to be effective in the fields of computer science (Devolder, Braak, & Tondeur, 2012).

**Aim of this study**

Engaging in modeling supports students authentic engagement in science and leads to teaching students the process by which science is conducted. Building upon previous research, this current study aims to contribute to the field by designing a modeling activity and research the influence of the built-in support. When engaging in the modelling activity the focus lies on the development of modeling performance, learning to reason on models and the understanding of models. In the following, the target group, modeling tool and the content topic will be described and explained. Thereafter the expected learning outcomes when designing and using a model will be discussed as well as the potential for including fitting scaffolds. Finally, the research questions will be specified before moving to the method.

## 2. Theoretical Framework

### Target group

This study focuses on young children and their engagement in models. Literature review has shown that studies on modeling in primary school concerning young learners are scarce (Louca & Zacharias, 2012). This can be explained by the fact that there is a general feeling that the modeling process is too difficult for young children. (Gilbert & Boulter, 2012). Modeling is indeed a difficult task and it has been argued that 11-12 year olds are unable to design their own model and understand the components (Penner, 2000). However, it has also been argued that modeling should be a central aspect of early education and be included in primary education (Lehrer & Schauble, 2000). From the age of six to eleven children develop problem solving skills, acquire the ability to reflect on their own behavior and goals (Eccles, 1999) and learn to reason on a more concrete level (Poland, van Oers, & Terwel, 2010). These skills are all needed to engage in modeling and research has shown that indeed seven-year-old children were able to design and use their own model (van Joolingen et al., 2014). To succeed in modeling, young children have to be approached differently and in a simpler manner than older children (Osborne, 2014). Most modeling tools require learning of specific syntax, which typically consist of programming code, equations, or graphical diagrams (Bollen & van Joolingen, 2013). To allow young children to engage in modeling, modeling tools should be designed in a fitting way, with the right amount of support and easy usability so that it connects to the target audience.

### SimSketch

In this study SimSketch, the recently developed modeling tool by Bollen & van Joolingen (2013) will be used. SimSketch is a drawing-based modeling tool, which makes use of drawings instead of using syntax for programming or writing mathematical expressions. In SimSketch the student can draw all the objects and entities they need to perform a task. For example, when designing a model on the solar system, students can draw the earth, the moon and the sun. Consequently, they then use the program to assign characteristics and movements to drawn entities. Once learners finish their drawing, they can run the program, meaning that the elements of the drawing start moving according to the behaviors assigned to them by the learner. In the case of the solar system this would be the orbit of the earth around the sun and the moon around the earth. Due to the model movement the learner gets direct feedback and can implement this immediately to optimize the model (Bollen & van Joolingen, 2013). Examples of other possible models in SimSketch are predator-prey systems, the action potentials in nerves and the concept of natural selection.

The educational potential of SimSketch has already been examined in an explorative study with young children by letting them create drawing-based models of the solar system. This study found that children were motivated to perform the modeling exercises and enjoyed completing tasks within the SimSketch environment. Because of the explorative character of this study no evidence was found that modeling influenced the children's learning outcomes, i.e. the pretest was the biggest predictor of posttest outcomes. That is why more research on children's engagement in SimSketch is needed. In the current study children aged from 7 till 16 will again participate in a newly developed SimSketch assignment to study their learning outcomes.

**Content Topic**

The topic of the current assignment was on traffic jam formation in a closed system without a bottleneck after the research by Sugiyamal, et al. (2008). The authors studied the phenomena of traffic jam formation without external influences such as accidents or roads crossings. An experiment was conducted where 22 cars drove on a roundabout at the same velocity of 30 km/h. All the car drivers were told to keep driving over the roundabout with the same speed. After a short amount of time cars had to brake and a jam formed caused by small differences in the velocity between cars. The research gave experimental evidence that the formation of a traffic jam is a collective phenomenon which is dependent on car interaction. Although no external influences were present, traffic jams could still form due to the behavior of different cars (Sugiyamal, et al., 2008).

To make a modeling exercise workable and effective it is important that children are able to use their prior knowledge which is why the topic of a common phenomenon was selected. The relative simple design of the experiment by Sugiyamal, et al. (2008) lends itself perfectly for a modeling exercise and recreation of the experiment into a modeling assignment in the SimSketch environment. Furthermore, dealing with a dynamic system that requires scientific reasoning becomes easier on a known topic (Rotherham & Willingham, 2010; Van Borkulo, 2009). And it is thus recommended to let novice modelers model phenomena of which they already have knowledge (Sins, Savelberg, & van Joolingen, 2005)

**Learning outcomes**

Louca & Zacharias (2012) state that the modeling process consists of four steps which should be initiated with a question or problem: (1) Making systematic observations: collecting evidence and using prior knowledge, (2) Constructing the model, (3) Evaluating the model; deployment of the model in a new situation and (4) Reconstructing the model. One's modeling performance is dependent on the ability to construct and reconstruct the model. After making a valid model one can go through the modeling cycle several times and go from a simple towards a more advanced model with higher explanatory capacity. The learning process takes place via reconstruction and adaptation of the model (Louca & Zacherias, 2014). During this stage, learners need to critically consider the model and change it where necessary, in other words, they adjust their hypothesis. In this study two main areas of learning and skill development can be distinguished: model-based reasoning skills and the understanding of models in a scientific context (Gobert, Snyder, & Houghton, 2002).

Model-based reasoning skills concern one's ability to (scientifically) reason about a model (Magnani, Nersessian, & Thagard, 1998) and to understand the relation and interaction between different variables in a complex system. Model-based reasoning can be divided in three types of skills: creating the model, applying knowledge on the model and evaluating the model (Van Borkulo, 2009). First of all, reasoning skills are needed to create the model and search for the correct external representations of the mental model. Second, one should be able to apply prior knowledge and to predict and explain the behavior of the model. For example to understand the influence on a variable when another variable is adjusted. The ability to predict and explain model behavior has been researched in 12-16 year old students and showed that although most students found modelling difficult, they were able to reason on the model when only three to four variables were present (Bliss, et al., 1992). The third aspect of model-based reasoning is the ability to evaluate the model on previous predictions and testing the hypothesis. Model-based reasoning has been studied to increase on all skills in 16 and 17 year old students after working with a model when compared with direct instruction and simulations (Van Borkulo, 2009).

The second area of learning discussed here is on the epistemological understanding of models: understanding of the nature of models and their use in science. It is expected than when designing and adjusting models this will lead to a better understanding of models (Grünkorn, Upmeier zu Belzen, & Krüger, 2012). Grosslight, Unger, Jay, & Smith (1991) describe three levels at which models can be understood. At level 1 students see models as exact copies of the original and aim to match the model in all dimensions to original. At level 2, they no longer see models as exact copies and understand that models have a purpose such as solving a problem. At level 3 they understand that the model is used for testing and changing variables to explain the original. Furthermore, they understand that the model can be used to test hypothesizes and draw conclusions (Grosslight, et. al, 1991). This understanding can be measured in five different aspects: (1) nature of models: a model is a theoretical reconstruction (2)multiple models: different forms of models can exist concerning one topic, (3) purpose of models: models are used to test predictions, (4) also with younger testing models: to make sure the model fits the reality and gain new insights and (5) changing models: due to model findings it is possible that a model changes (Grünkorn, Upmeier zu Belzen, & Krüger, 2012). In appendix 2B a description of the understanding at different aspects per level can be found.

Due to the similarities of modeling with real scientific inquiry it is stated that the understanding of how models work implies that one understands how science works (Gilbert, 2015). Research has shown that most children between 11 and 15 are at level 1 or level 2 but not at level 3 (Grünkorn, Upmeier zu Belzen, & Krüger, 2012). Increase of model understanding has been studied in middle school students after participating in a two week course on modeling plate tectonics. This showed that when working with model the understanding of models and their use in science increase (Gobert, Snyder, & Houghton, 2002).

**Scaffolds**

Evidence of positive learning outcomes of novice learners of modeling exercises is scarce. This can be explained by the fact that forming a model is, especially for young, novice modelers a complex exercise. Novice learners often do not use effective experimentation strategies and are have difficulty with in-depth interpretation of their results (Löhner et al., 2004). To be successful in modeling, learners should learn to regulate their own learning process and learn how to deal with such a program and which strategy should be used.

For this, guided learning with inclusion of scaffolds, examples, and feedback is preferred (Alfieri, Brooks, & Aldrich,

2011) in which the authentic aspect of modeling is maintained. When not included and the assignment is unclear this could lead to usability problems and distractions which lead to lower or no learning outcomes. A recent review article on the function of scaffolds in supporting self-regulated learning describes the positive influence of build-in computer scaffolds can have as strategy activators and in regulating student cognition and behavior (Devolder, Braak, & Tondeur, 2012). Young learners mostly benefit from scaffolds that helps them to define and plan the task and by doing so increase their task value. Also the inclusion of hints or feedback which monitors their learning process leads to higher learning outcomes. Furthermore it shows that required scaffolds are preferred over optional scaffolds to evoke information seeking strategies (Simons & Klein, 2007).

When working with novice learners who perform a relative simple modeling experiment it is important to urge them to change only one variable at a time (Denker, 2003). This way they are able to interpret and understand the outcome in an easy way, examine one aspect at a time and adjust and improve the model in every cycle. To promote the strategy of changing one variable at a time the use of prompt questions are most suitable. Prompt questions are effective in guiding student learning, lettings students plan their activity, promote the right strategy and enhancing the learning outcomes in a positive way (Devolder, Braak, & Tondeur, 2012).

**The current study**

The main goal of this study is to gain insight into children's modeling process and learning outcomes under the influence of scaffolds. In this study the focus lies on four aspects: First of all, the ability of young children to make a model will be researched. Secondly, the influence of prompt questions on children's modeling performance is examined. The inclusion of prompt questions which focus on changing one variable at a time is hypothesized to benefit children's modeling performance. Furthermore, the posttest scores and assignment behavior are compared between the control and scaffold condition. Thirdly, the interaction of modeling performance and learning outcomes will be studied. The learning outcomes studied are model-based reasoning and understanding of models. It is hypothesized that high model performance will lead to higher learning outcomes as has been found in previous research. Finally, the influence of age on model performance, learning outcomes and motivation is studied to determine for which age group the inclusion of modeling in the curricula is most favorable.

In the end this study has the intention to answer the following questions:

1. Can young learners create a model?
2. Do prompt questions have a positive influence on modeling performance?
3. Is there a relation between modeling performance with model-based reasoning and understanding of the nature of models?
4. What is the influence of age on model performance, model-based reasoning, understanding of the models and motivation?

## 3. Method

### 3.1Participants

A total of 469 visitors of the NEMO science museum aged between 7 and 16 years old have participated in this research. In total 36 participants were excluded from the data due to practical matters such as software malfunction, excessive external help (for instance by parents), non-native Dutch speakers or premature quitting. Of the remaining 435 participants, 185 were girls and 232 were boys and for 18 participants gender and age were unknown. Figure 1 displays the distribution of participants over age and gender.

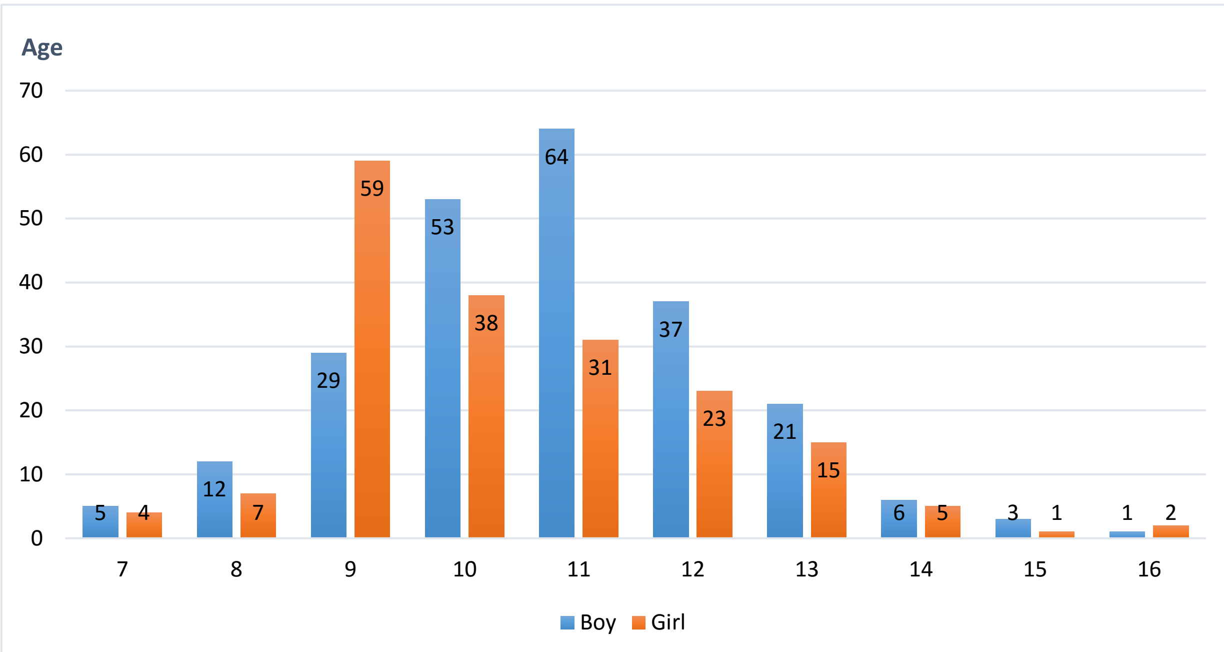


*Figure 1: Demographic representation of the total 417 participants*

### 3.2Design

A two group experimental design with random assignment to each group was developed. Participants were divided into either the scaffold condition (N=218), or the control condition (N=216). In both conditions, participants performed an assignment concerning a modeling exercise on a tablet. The assignment was designed for this study and consisted out of six steps: (1) Introduction which stated that participants would act as real researchers to solve a problem, (2) Video on Content, (3) Pre-test, (4) Video on SimSketch, (5) Modeling exercise and (6) Posttest. The modeling exercise differed between the two experimental groups in the amount of built-in support. In the scaffold condition, five obliged prompt questions were added compared to the control condition. Data was plotted and all participants' actions could be analyzed afterwards.

**3.3Materials**

The main part of the assignment for the participants was to create and use their own model on traffic jams in SimSketch. Figure 2 shows the opening screen of the assignment.


*Figure 2: Assignment opening screen: users could navigate through the program by selecting the symbols on the right*

**3.3.2 Create traffic jams in SimSketch**

Due to the young age of the participants, the number of modeling options was limited and only the essential elements were included: the road and the car. After drawing these elements three characteristics could be assigned to the car: "Follow route", "car factory" and "avoid collisions". "Follow route" made the car move over the road, and users could decide the *speed* and *acceleration* speed of the car. The next step was to include the "car factory" in which the *total amount of cars* could be set. Also *the waiting time between cars* to go on to the road could be adjusted as well as the *speed variation*. Speed variation signifies the amount of speed the cars on the road could differ from the speed set in the "follow route". The "avoid collisions" gave the car *brake sensors*. One could adjust the reach of these sensors and the car's *brake speed* in response of seeing another car. Figure 3 shows the SimSketch learning environment build into the assignment.

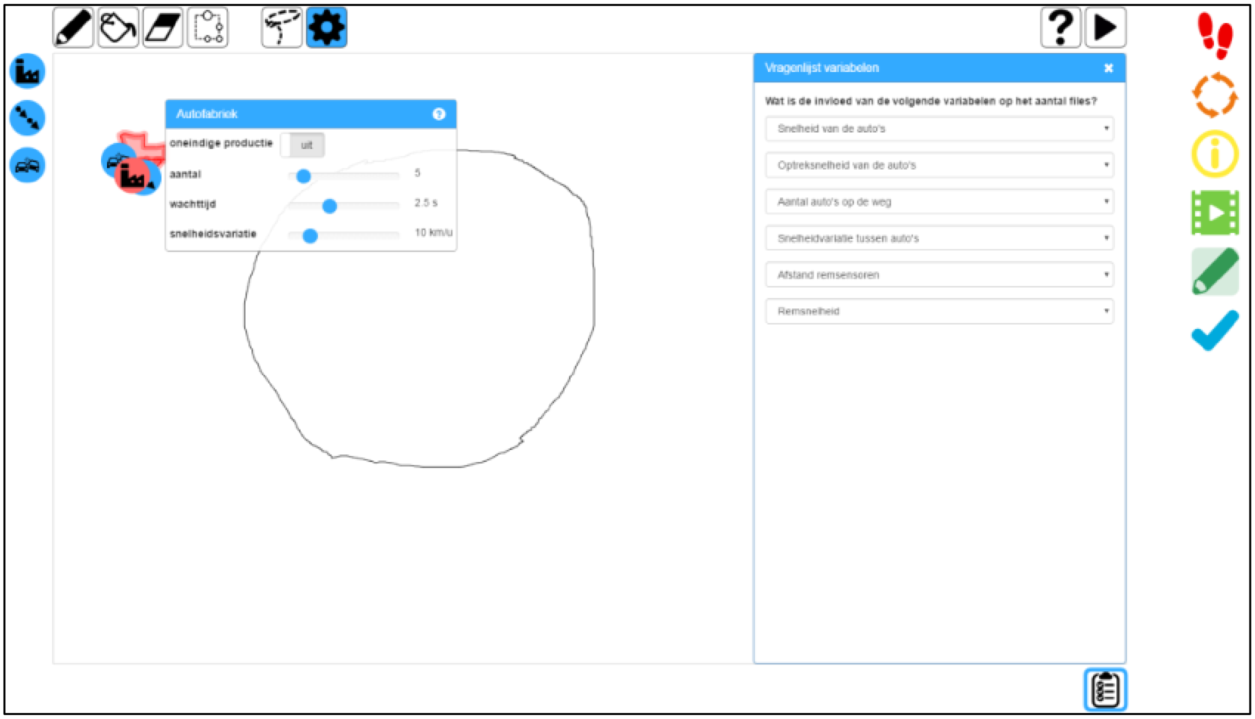


*Figure 3: SimSketch environment with prompt questions.*

### 3.3.3 Prompt questions

Participants in the scaffold group were supported by six guiding multiple-choice prompt questions which are showed in figure 3. Every question concerned one of the different adjustable variable possible in the model. The participants had to answer in what way that specific variable influenced the formation of traffic jams. For example, to answer the question on speed of cars the participant could choose between three different sentences: "More jams form when the velocity is high/More jams form when the velocity is low/ Velocity does not influence jam formation". Because all the variables were in interaction with each other, there was no good or wrong answer, the prompt questions were only used as a strategy promotor. When starting with SimSketch the prompt questions were visible but participants could close them while forming a model. To make sure the prompt questions were used participants could not proceed to the post test before filling in all the prompt questions, after the study by Simons & Klein (2007).

### 3.3.4 Explanation video's

A total of two explanatory movies were shown. The first one was a short part of the experiment conducted by Sugiyamal, et al.( 2008) and showed cars driving around a roundabout (the orange symbol in figure 2). This movie was included to activate participants' knowledge, to make them enthusiastic about the subject and to promote their motivation (Pintrich & De Groot, 1990). A voice-over explained the experiment and ended by stating that in this assignment they would research the cause of this behavior.

The second movie was a three-minute video on how to use SimSketch to design a model on traffic jams with a voice over explaining all the steps and variables as well as what was meant with the term variable. In the scaffold condition it was stated that it was important to answer the questions while making and adjusting the model.

### 3.3.5 Supporting features

The pilot had shown that the participants found it difficult to let the car move over the road in SimSketch. Therefore, a question mark button was introduced (see figure 3 in the upper right corner) which gave hints on what to do when the model was not working. When participants did not understand one of the three characteristics they could click on the characteristics' question mark as well, in which case they would get to see that part of the explanatory video again.

### 3.4Experimental Measures

The complete pretest and posttest can be found in appendix 1.

### 3.4.1Pretest

A three question open-ended pretest was included after seeing the introduction movie. The pretest was designed to estimate participants' ability to answer open questions and their knowledge on the topic. In the analysis the pretest was used to control for posttest scores. Out of the three questions, two matched the posttest.
A pilot study had determined the task took approximately 30 minutes. Since this is quite long when visiting a museum, it was decided to keep the pretest short instead of including a pretest that would match the posttest. Additionally, the posttest asked specialized questions about the modeling assignment which could not be answered before performing the modeling exercise.

### 3.4.2 Posttests

A total of four questions assessed children's ability to reason about their model. The questions were inspired by the work of van Borkulo (2009) who developed multiple questions to assess one's ability to apply knowledge on models and to evaluate models.
To measure the nature of models the five questions posed in the research by Grükorn, Upmeier zu Belzen, & Krüger (2012) were used. Every question was on one aspect of the nature of models in the context of traffic jams.
A ten item motivational questionnaire with a 4-point Likert scale was added. The questionnaire consisted of five question concerning perceived competence and five on valuing of the assignment.

### 3.5 Procedure

Data collection took place in the NEMO science center for five weekends in a row inside their "Research & Development room", where 8 tablets were placed on tables. Participants were placed behind one of these tablets and were told that the data would be used for scientific research on how children learn and that is was important that they did the assignment individually.
After the instructions on navigating through the assignment were given they were allowed to start and assigned to

the control or scaffold group with a random generator. They worked by themselves and if they had really urgent questions they were allowed to ask the researcher or the assistant.

**3.6 Coding and scoring**

**2.6.1 Help seeking behavior**

Children could raise their hands to ask for support. To make sure that all participants got the same treatment and to increase the reliability, the question would not be answered but instead participants were instructed to watch the explanatory movie again or to click on the question mark button. However, when participants still could not proceed and asked again the answer was given by the researcher, who would note this in a table. Participants were helped and classified into three different groups (1): children who were told to look at the explanatory movie again or check the question mark. (2) Children who were explained a certain step like how to put the car on the road. (3) Children who were helped for a long time in multiple steps. To make sure all children were helped equally the first time they raised they hands they would always be told to look at the movie or check the question mark. Only when children had multiple question more help was provided.

3.6.2 Scaffold use

The prompt questions were intended to let participants use the strategy of changing one variable at a time. During the study however, it became clear that a lot of participants filled in the prompt questions all at once, either at the beginning of SimSketch exercise or right before they could move on towards the posttest. This led to the categorizing into three scaffold levels: (1) control group, no questions, (2) scaffold group, answering the questions independently of the modeling activity and (3) scaffold group, answering the questions in interaction with the use of SimSketch. To classify participants into one of the three levels, the number of times participants opened the questions and the number of times answers were given were taken out of the plots.

3.6.3 Modeling performance

According to Boohan & Brosnan (1994) when evaluating a model one should focus on the necessary components of models. These include representation of physical objects, physical concepts (object characteristics and object states), and their relationships.

All models were rated and classified into three different categories for which points were given: no valid model (0 points), valid model (1 point) and validated model through experimenting (2 points). In the explanatory video on SimSketch it was explained how to design a working model and children who did not manage to do this got 0 points. Children who were able to let the model run while all three characteristics were correctly assigned to the drawn elements got 1 point. Because learning takes place when adjusting and reconstructing the model (Louca & Zacharias, 2012) participants who experimented more than 5 minutes while changing the model more than 4 times were classified in the last category and received 2 points.

### 3.6.4 Coding rubrics

For all open ended questions answers were classified into categories ranging from category 0 to 2 or 0 to 3. The students understanding of models posttest was based on the work by Grükorn, Upmeier zu Belzen, & Krüger (2012). In the pretest and model-based reasoning posttest the coding rubric was designed based on the answers children gave during the pilot. The pretest and model-based reasoning coding rubric can be found in appendix 2A and the nature of models rubric can be found in appendix 2B

### 3.7Analysis

For the open ended questions on scientific reasoning and the nature of modeling two second raters both coded one of the domains. The rule raised by Cicchetti, (1976) on the amount of participants that should be rated was used: $N \geq 2k^2$, in which k is the amount of rating skills per question. This resulted in 32 participants per question. The interrater reliability of the answers was measured by Cohen's Kappa. Cohen's Kappa = 0.584 which is considered reasonable.

In the motivational questionnaire, question 5 and 9 were reversed and a principal component analysis with a Varimax rotation was performed. This showed that the questionnaire measured two constructs: perceived competence and valuing. Item 6 and 3 had to be taken out due to insufficient reliability and item 7 measured valuing instead of competence. Competence was measured by six items and had a good reliability (α=0.769) and valuing was measured by two items with a reasonable reliability (α=0.671) (Table 1). Although two items are suboptimal this was preferred over the low internal consistency or excluding the component of valuing completely. ANOVA's were performed on the difference between variables in the scaffold conditions. ANCOVA's with a pretest covariate were performed for the relation of modeling performance on model-based reasoning and understanding of the nature of models. For all the significant ANOVA's in the research questions the partial eta squared was calculated as a measure of effect size. Here, the general rules of thumb given by Miles & Shevlin (2000) is used, who consider 0.01 small, 0.06 medium and 0.14 as a large influence. Also, for the significant ANOVA's post-hoc comparisons where conducted (Bonferroni).

A Pearson correlation matrix was computed, for which 0.1 is considered a small, 0.3 a medium and 0.5 as a large effect (Miles & Shevlin, 2000).

Table 11: Distribution of motivational questionnaire items

| Construct | Item | Question |
|---|---|---|
| Competence | Item 5 | I found it hard to work with the program |
| | Item 9 | I found it difficult to let the model move |
| Valuing | Item 2 | I found the modeling exercise interesting |
| | Item 3 | I liked to think about the formation of traffic jams |
| | Item 4 | I found it nice to work with SimSketch |
| | Item 7 | The model helped me to better understand the formation of traffic jams |
| | Item 8 | I enjoyed watching the model move |
| | Item 10 | The movement of the model helped me understand the formation of traffic jams |

## 4. Results

**Research question 1: Children's ability to design a model**

A total of 435 children started the assignment of which 357 participants completed the whole assignment and 239 where able to create a valid model. Of the children who made a valid model 105 experimented for more than 5 minutes in which they changed their model 4 times or more. Children who weren't able to create a valid model tried for an average of 17,6 minutes before they gave up and moved to the posttest. For children who were able to make a model it took on average 17,3 minutes to make a valid model.

**Research question 2: The effect of prompt questions on model performance**

The data showed that of the 219 participants in the scaffold condition 163 filled in the prompt questions at once during the SimSketch exercise. This could either be immediately in the beginning before developing a model or at the end before moving to the posttest. The other 56 participants used the questions integrated with the model meaning that they switched between filling in the question and modeling. They thus filled in the prompt questions in multiple times, ranging from 2 to 8 times.

A one-way ANOVA showed that there is a significant relation between scaffold use and model level ($F(2,429)= 4.89$; $p=.008$; $\eta^2 = .022$) which is a small effect size (Miles & Shevlin, 2000). Post-hoc comparison (Bonferroni) showed that the model level is significantly different when the questions are used integrated compared with the control group ($p=.008$) and the group who used the questions separately ($p=.016$). Table 2 shows the scores on other variables on the different scaffold conditions. One-way ANOVA's where performed on reasoning, model understanding, time on task and age.

A one-way ANOVA showed no significant relation between scaffold level and model-based reasoning $F(2,373)=1.786$, $p=.169$, but a significant relation between scaffold level and model understanding was found $F(2,357)=5.557$, $p=.004$, $\eta^2= .030$. Post-hoc comparison (Bonferroni) showed a significant difference of the integrated question use between question use separately ($p=.006$) and the control group ($p=.007$).

Post hoc comparisons (Bonferroni) where performed on the separate questions in the understanding of models posttest. Participants who used the questions integrated scored significantly higher on the aspect of nature of models than the control group did (p=.013) and the group who used the questions separated (p=0.34). The same accounted for the aspect of changing models were the integrated group scored higher than the control group (p=.005) and the group who used the questions separated (p=.028).

No significant relation was found between the scaffold level and the time on task $F(2,430)=1.789$, $p=.167$). A significant relation between scaffold level and age was found $F(2,414) =4.112$, $p=.017$, $\eta^2 =.019$. Post hoc comparison (Bonferroni) showed only a significant difference between the control group and the group who used the questions integrated ($p=.013$).

Table 2: Differences in mean and standard deviation between scaffold conditions

| | Control condition | | | Experimental Condition | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | Total | | | Separate | | | Integrated | | |
| N | 214 | | | 219 | | | 163 | | | 56 | | |
| N with valid model | 111 (51%) | | | 130 (60%) | | | 89 (55%) | | | 41(73%) | | |
| | N | Mean | (SD) | N | Mean | (SD) | N | Mean | (SD) | N | Mean | (SD) |
| Model performance* | 214 | .75 | (.82) | 219 | .84 | (.796) | 163 | .76 | (.769) | 56 | 1.09 | (.808) |
| Pretest | 206 | .24 | (.20) | 211 | .27 | (.20) | 155 | .27 | (.20) | 55 | .27 | (.20) |
| Reasoning | 184 | .24 | (.26) | 191 | .30 | (.29) | 135 | . 30 | (.28) | 55 | .28 | (.30) |
| Understanding* | 174 | .20 | (.14) | 183 | .22 | (.15) | 129 | .20 | (.15) | .54 | .27 | (.14) |
| Valuing | 157 | .75 | (.14) | 164 | .77 | (.14) | 117 | .77 | (.14) | 47 | .77 | (.14) |
| Competence | 175 | .68 | (.22) | 182 | .68 | (.22) | 129 | .67 | (.22) | 53 | .72 | (.21) |
| Time on Task (sec) | 214 | 1605 | (728) | 218 | 1635 | (610) | 163 | 1593 | (688) | 56 | 1782 | (465) |
| Time on posttest (s) | 214 | 388 | (303) | 218 | 367 | (298) | 163 | 349 | (325) | 56 | 426 | (189) |
| Help Seeking | 214 | 2.4 | (3.3) | 218 | 2.3 | (3.5) | 163 | 2.2 | (3.5) | 56 | 2.3 | (3.2) |
| Age* | 205 | 10.5 | (1.6) | 212 | 10.8 | (1.7) | 157 | 10.6 | (1.7) | 55 | 11.2 | (1.7) |

**significant difference of $p<.05$ between the group who used the questions integrated and the other groups*

**Correlation matrix**

A Pearson correlation matrix was made for the eleven main variables in this study. Of the 55 possible correlations 31 are significant at the .05 level. The correlation matrix does not show strong correlations according to Miles & Shevlin (2000). Medium-high correlations can be found between age and the understanding of models posttest and between the models posttest and the pre-test. Furthermore, it is shown that age has a significant correlation on all variables including a negative correlation with help seeking and questions asked. This implies that younger children asked more questions during the study.

Table 3: Pearson correlation matrix

| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1. Age | 1 | | | | | | | | | | |
| 2.Model perform | .137** | 1 | | | | | | | | | |
| N= | (414) | | | | | | | | | | |
| 3.Scaffold level | .141** | .110* | 1 | | | | | | | | |
| N= | (417) | (432) | | | | | | | | | |
| 4.Time on Task | -.176** | .329** | .081 | 1 | | | | | | | |
| N= | (415) | (432) | (433) | | | | | | | | |
| 5.Post-reasoning | .236** | .181** | .074 | .008 | 1 | | | | | | |
| N= | (367) | (375) | (377) | (375) | | | | | | | |
| 6.Post-models | .437** | .170** | .139** | .027 | .346** | 1 | | | | | |
| N= | (353) | (358) | (360) | (358) | (358) | | | | | | |
| 7.Pretest | .319** | .208** | .067 | .104* | .279** | .440** | 1 | | | | |
| N= | (402) | (412) | (415) | (413) | (371) | (354) | | | | | |
| 8.Valuing | -.296** | -.170** | -.059 | .054 | -.192** | -.251** | -.221** | 1 | | | |
| N= | (315) | (319) | (321) | (319) | (318) | (318) | (315) | | | | |
| 9.Competence | -.117* | .192** | .048 | .157** | .094 | .110* | .106 | -.057 | 1 | | |
| N= | (351) | (355) | (357) | (355) | (354) | (353) | (351) | (319) | | | |
| 10. Help seeking | -.184** | .048 | -.016 | .229** | -.018 | -.046 | -.077 | .030 | -.240** | 1 | |
| N= | (415) | (432) | (433) | (433) | (375) | (358) | (413) | (319) | (355) | | |
| 11. Questions asked | -.206** | .067 | -.005 | .132** | -.040 | -.056 | -.090 | .062 | -.103 | .198** | 1 |
| N= | (417) | (432) | (435) | (433) | (377) | (360) | (415) | (321) | (357) | (433) | |

*$p<0.05$, **$p<0.01$ PEARSON CORRELATION*

**Research question 3: The effect of model level on learning outcomes**

Table 4 shows the mean scores and standard deviation on the two posttest between the three modeling groups.

Table 4: Posttest scores on model performances

| | Model-based Reasoning | | | Nature of Models | | |
|---|---|---|---|---|---|---|
| | N | Mean | (SD) | N | Mean | (SD) |
| No Valid model | 147 | .195 | (.238) | 140 | .183 | (.146) |
| Valid model | 131 | .320 | (.289) | 125 | .224 | (.149) |
| Valid model and experimented | 97 | .308 | (.275) | 93 | .244 | (.133) |

An ANCOVA was conducted to determine a statistically significant difference between reasoning scores on the different modelling skills with the  pretest score as a covariate. A significant difference was found on modeling performance and the score on model-based reasoning after controlling for the pretest, $F(2,372)=4{,}97$, $p=.007$ $\eta^2=.027$). Also a significant relation between the pretest and the model-based reasoning posttest was found $F(1,372)=23{,}3$, $p<.0001$ $\eta^2=.060$). Post-hoc comparison (Bonferroni) showed that the mean scores for scientific reasoning were significantly different between no valid model and a valid model ($p<.001$) and between no valid model and validated model through experimenting ($p=.004$), but not between the children who made a valid model and who validated the model through experimenting ($p=.730$). Post hoc comparisons (Bonferroni) for the independed questions of the model-based reasoning posttest were performed. This showed that the difference in overall posttest scores was significantly higher on the two open ended questions ($p<.001$) for children who were able to make a valid model compared to the children who were unable to make a model. The multiple choice questions did not differ significantly between the types of model performance.

A one-way ANCOVA test showed that there was no significant relation between model performance and the understanding of models posttest when controlling for pretest score. $F(2,358)=1{,}12$ $p=.327$. There is a significant relation between pretest score and the score on the understanding of models posttest $F(1,358)=71.6$ $p<.001$; $\eta^2=.171$.

Both results imply that the pretest was the best predictor for both posttest. However, modeling performance was positively related to model-based reasoning.

**Research question 4: Age trends in modeling performance, posttest scores and motivation**

Figure 4 shows the influence of age on modeling performance, posttest scores and the motivation aspects. This shows that the posttest scores increase with increasing age but that the 7 and 8 year olds performed better on reasoning than the 9 year olds. This is also the case for modeling performance, where 7 and 8 year olds outperform children of age 9. The modeling performance also show a big decline in 14 year and older children. Competence levels increase with age, with the exception of the 7 and 8 year olds and valuing levels decrease with age.

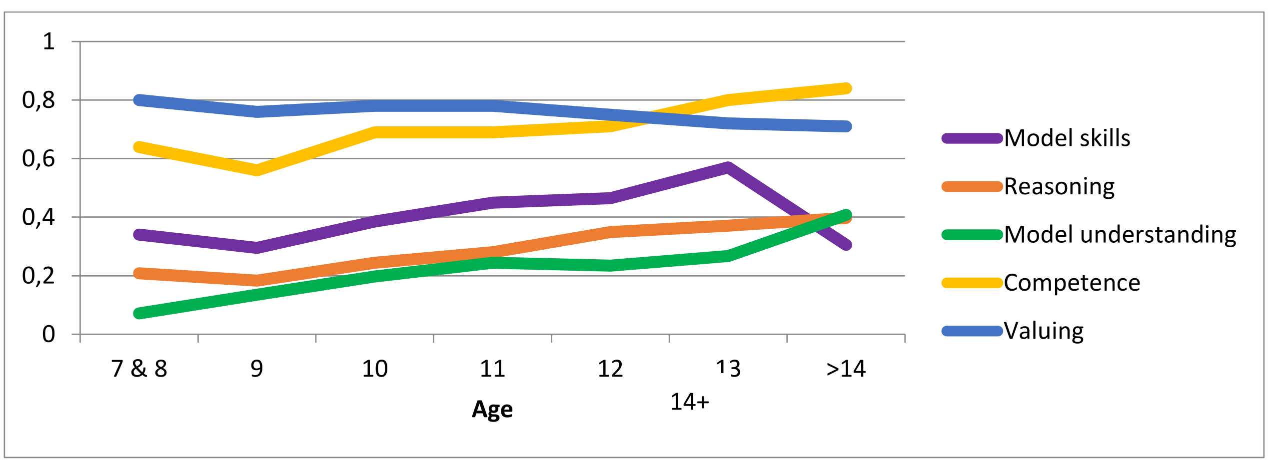


*Figure 4: Modeling performance, posttest scores and motivational aspects for different age classes*

## 5. Discussion & Conclusion

The aim of this study was to contribute to the field by designing a modeling activity and research the influence of the built-in support. This was operationalized in four research questions which will now be discussed in more detail. The first question studied whether children were able to design a model. The results show that 56% of the children were able to design a valid model. In total 24% of the children spend time reconstructing and adjusting the model. This outcome is relatively low but in line with previous research which reported that construction a model is very hard for children (Gilbert & Boulter, 2012).

The second question that this study aimed to answer is whether the inclusion of prompt questions leads to more and better model performance. The results show that the inclusion of prompt questions can be an effective scaffold but that this depends on the way the scaffolds are used. When participants filled in the questions all at once there was no significant difference on children's modeling performance or learning outcomes when compared to the control group. However, participants who used the questions integrated, meaning that they switched between filling in the questions and adjusting and using the model, scored higher on modeling performance. To use the prompt questions integrated is in line with the intended strategy to change only one variable at a time. This prompt question use may have led to better model performance because more time was spent on adapting and running a valid model. Here, also the opposite could be the case and children who spent more time on adapting and running a model also changed and opened the prompt questions more frequently. Which way this interaction goes should be further studied in future research.

Interestingly the scaffold use also shows a positive relation with the score on the understanding of models. For the children who used the questions integrated this was significantly higher on the aspects of the nature of models and changing models. This implies that when someone uses the strategy of changing only one variable at a time this leads to a better understanding of the nature of model and thus of the nature of science. This can be explained by the fact that this strategy is seen as a core strategy in science and especially useful for young children (Denker, 2003). This results also imply that when changing the model with the help of a strategy one becomes aware of why models should be changed.

In the third research question the relation between modeling performance and the model-based reasoning and understanding of models was tested. First of all, the results showed that the pretest was the biggest predictor for both posttest score which was in line with other research on SimSketch (van Joolingen, et al., 2014). Secondly, it showed that when participants were able to make a valid model they scored significantly higher on model-based reasoning than children who were unable to make a model. This indicates that children are able to predict, explain and evaluate the model behavior in interaction with the modeling performance. No significant relation was found between model skill and understanding of models. This difference could be explained by the way the questions were posed. The reasoning posttest asked question about the model and whether the participant had found the correct variables explaining the behavior. The understanding of models posttest asked more general question on models and was less dependent for the right answers on being able to make a valid model. In both posttest scores the children who spend more time adjusting and reconstructing the model did not show higher learning outcomes. Only the ability to design a valid model determined learning outcomes which is contradictory with previous research (Louca & Zacharias, 2012). A possible explanation is that the children who already understood the model did not feel the urge to experiment with it and still scored relatively high on both posttests.

In the fourth research question the influence of age on model performance and both posttest scores were addressed. The data showed that for both posttest scores and model performance a fluent increase was present with only the seven and eight year olds being the exception. The fact that they scored relatively high is probably due to chance because of the small amount of children in this age group. Modeling performance showed a fluent increase but dropped in score with children of 14 years and older. It is unlikely that this is caused by incompetence but rather because the participants were bored and the exercise did not appeal to them. This trend is also visible in the valuing component which declines with age. Again, it is important to realize that this group was very small and thus subject to chance. Still, because the time on task correlates negatively with age it seems that older children will benefit from a more challenging assignment. For example, more variables could be included or a more complex phenome should be studied.

**Limitations**

The location of the research in the science center had the advantage that there were a lot of children available what resulted in a high sample size. This had the disadvantage that the intervention time had to be around 30 minutes. Through this, the explanatory movie on SimSketch was very short and all the SimSketch steps were explained very quickly. Together with the difficulty of a modeling exercise in general this may have led to poorly understanding SimSketch and explain why only 56% of the children was able to make a valid model. Not only the use of SimSketch but the assignment in general was too difficult for children and in the answers a lot of children said something like “sorry but I really don’t know”.

In general all the children showed only a small understanding of models and especially young children scored low on the understanding of models posttest. A score of 0.33 in figure 4 would imply being at level 1 and only children of 14 years and older had an understanding of models at level 1. This is in line with the research by Grükorn, Upmeier zu Belzen, & Krüger (2012) who measures children’s understanding of models without previous instruction on the topic of models. Their study showed that of children between 11 -15, most but not all were in level 1 or 2. For young children to gain knowledge on the understanding of models a longer intervention time is probably needed as in the research by (Gobert, Snyder, & Houghton, 2002). They let children participate in a two week course and found increase of children’s understanding of models.

Furthermore, due to the informal setting a lot of children gave very short answers on the questions which made it hard to measure their real score on all the experimental measures. Still, the importance of including open ended questions is stressed by this research when looking at the model-based reasoning posttest. Children who were able to make a valid model outperformed the children who were unable to make a valid model only on the open questions and not on the multiple choice questions. Due to the big chance of guessing correctly the multiple choice questions were less discriminating on reasoning skills than the open ended questions. To gain a complete view of children's thinking, interviews or more extensive answers are preferable in future studies to gain a more thorough view of children's understanding of models.

**Implementations/Future research**

This study showed the benefits the inclusion of prompt questions can have on modeling performance, provided that they are used in the right way. However, the majority of the participants used the questions separately (75%) instead of integrated in the modeling activity. A possible explanation is that participants did not understand the function of the prompt questions and treated the assignment as something they needed to finish instead of something they could learn from. During modeling the children frequently asked: "am I ready now, is this it?" which is in line with the research by Sins, Savelberg, & van Joolingen (2005). They found that the novice learners did not see the modeling exercise as scientific but more as a problem in which a model needed to be constructed that would look exactly like the original. Also Löhner, et, al. (2004) found this phenonema and described that the students spend a lot of effort in trying to match their model to the orignal.

The data showed that the children who used the questions integrated where significantly older than children in the other groups. This might be explained by a bigger chance that they have done an exercise like this before or have more experience with discovery learning in an unstructured environment. In general the younger children needed more support and asked more questions and showed more help seeking behavior than older children. This suggest that there was not enough in-built support or that they were unable to work with the in-built support. To support them in working with the prompt questions research shows the importance of teachers as a form of scaffold to guide students through the modeling process (Louca & Zacharias, 2012). Another option is to implement more built-in support that helps children to work with the prompt questions as they were intended. Here, research points to the inclusion of multiple scaffolds which can have a positive influence on the learning outcomes (Devolder, Braak, & Tondeur, 2012). Concretely this implies that the modeling exercise should be assisted by another built-in scaffold which puts focus on using the questions integrated in the model. In this assignment, the inclusion of a scaffold that helps structure the different steps of the assignment could be effective. For example the inclusion of a constant present overview of the experimental procedure. This has been used in the research by Chang, Chen & Lin (2008) and proved to help children plan and organize their behavior. This inclusion could guide learners through the steps they need to take (make a model, read the questions, change your model, answer one questions, change your model, answer another question etc.). Future research should thus focus on the development of an assignment with more scaffolds to make sure all children can benefit from the support.

Overall, this study showed the potential of letting children participate in a modeling assignment. It proved that models can be included into the curricula of early science education to let children engage in scientific practices already at a young age. With the help of models children are able to reason on complex phenomena and act as if they are scientists themselves. Although more research is needed, using and designing models is indeed very promising for science education.

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**Appendix 1A Pretest**

1. Hoe oud ben je?

2. Ben je een jongen of een meisje?

- Jongen
- Meisje

3. In Nederland bestaat 1 op de 5 files uit de zogenaamde spookfiles die je net zag. Files die er eigenlijk niet hoeven te zijn. Kan je na het zien van dit filmpje al een reden bedenken hoe dit soort files ontstaat?

4. Je gaat nu onderzoeken hoe dit soort files ontstaat met behulp van een model. Wat is volgens jou een model?

5. Waarom denk je dat wetenschappers modellen gebruiken?

Wanneer je alles hebt ingevuld klik dan op het volgende symbool. Daar krijg je een filmpje te zien waar je wordt uitgelegd hoe je met het programma SimSketch een model kan maken en files kan onderzoeken.

**Appendix 1B Posttest**

Je bent klaar. Beantwoord nu de onderstaande vragen.

1. Wat zal je nu als reden geven over hoe deze files ontstaan?

2. Welke variabele is het belangrijkst voor het ontstaan van files?

- Optreksnelheid
- Remsensoren
- Remsnelheid
- Snelheidsvariatie
- Hoeveel auto's op de weg
- Snelheid

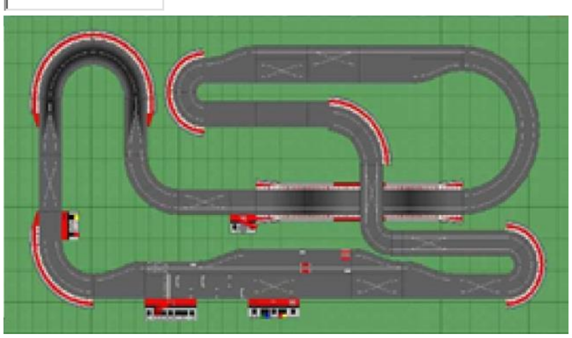
3. Klopt het dat wanneer alle auto's precies even hard rijden er dan heel veel auto's op de weg kunnen zonder dat er files ontstaan?

- Ja
- Nee

4. Frank heeft ook een model gemaakt in SimSketch. Het viel hem op dat er soms meer files ontstonden bij een hoge snelheid maar soms juist bij een lage snelheid. Kan je hier een verklaring voor bedenken?

5. In het model dat je net gemaakt hebt ontstonden files. In de echte wereld ontstaan er ook vaak files. In hoeverre komt het model dat jij net gemaakt hebt overeen met files in het dagelijks leven?

6. Hieronder zie je een afbeelding van een model waarmee andere wetenschappers ook proberen om filevorming te verklaren. Verklaar waarom er verschillende modellen kunnen zijn die files proberen te verklaren.



7. Waarom gebruiken wetenschappers modellen?

8. Leg uit hoe er getest zou kunnen worden of je met behulp van het model dat jij net hebt gemaakt files kan verklaren en oplossen.

9. Kan je redenen verzinnen waarom je model over filevorming zou moeten worden aangepast?

Tot slot nog een paar korte vragen over wat je ervan vond om mee te doen aan dit onderzoek met SimSketch

1. Ik heb al vaker gewerkt met dit soort computerprogramma's

○ Helemaal niet mee eens ○ Niet mee eens ○ Mee eens ○ Helemaal mee eens

2. Ik vond de modelleer opdracht interessant

○ Helemaal niet mee eens ○ Niet mee eens ○ Mee eens ○ Helemaal mee eens

3. Ik vond het leuk om over het ontstaan van files na te denken

○ Helemaal niet mee eens ○ Niet mee eens ○ Mee eens ○ Helemaal mee eens

4. Ik vond het leuk om met SimSketch te werken

○ Helemaal niet mee eens ○ Niet mee eens ○ Mee eens ○ Helemaal mee eens

5. Ik vond het moeilijk om met het computerprogramma te werken

○ Helemaal niet mee eens ○ Niet mee eens ○ Mee eens ○ Helemaal mee eens

6. Ik denk dat ik het model goed heb gemaakt

○ Helemaal niet mee eens ○ Niet mee eens ○ Mee eens ○ Helemaal mee eens

7. Het model heeft mij geholpen om het ontstaan van files beter te leren begrijpen

○ Helemaal niet mee eens ○ Niet mee eens ○ Mee eens ○ Helemaal mee eens

8. Ik vond het leuk om te zien hoe het model ging bewegen

○ Helemaal niet mee eens ○ Niet mee eens ○ Mee eens ○ Helemaal mee eens

9. Ik vond het moeilijk om het model te laten bewegen

○ Helemaal niet mee eens ○ Niet mee eens ○ Mee eens ○ Helemaal mee eens

10. Het laten bewegen van het model heeft mij geholpen bij het begrijpen van het ontstaan van files

○ Helemaal niet mee eens ○ Niet mee eens ○ Mee eens ○ Helemaal mee eens

Bedankt voor het meedoen aan dit onderzoek!

**Appendix 2A: Coding rubric Pretest/Model-based reasoning**

| | | Category / points received | | |
|---|---|---|---|---|
| Question | | 1. | 2. | 3. |
| What do you think a model is? | Description | Participants mention that it is something that can be built after realty | Participants understand that the rebuilt has a scientific purpose | N.a.v |
| | Example | Something that is rebuilt in miniature | An example of the situation that will be researched | |
| Can you give some explanations of why these kind of traffic jams form? | Description | Participants give a description of what they saw happening. | Participants understand that the jam is caused due to the relation between cars | Participants form a theory, state something bigger then the movie/model they just made |
| | Example | Someone in the front is pushing the breaks/ is to slow | Some cars drive faster than other cars | There is a difference in driving behavior between the cars |
| Can you explain why sometimes with high and sometimes with low velocity jams form? | Description | Participants describe what they think would happen. | Participants understand that other variables may influence and cause jam formation | Participants understand that the formation is about the interaction of different variables |
| | Examples | When you drive slowly you are too close together | The road is not good enough drawn<br>It also has to do with the acceleration speed | It has to do with the connection between speed/acceleration and breaking speed and how these are in relation to each other |

**Appendix 2B: Understanding of models**

| | | | Levels of understanding | | |
|---|---|---|---|---|---|
| Aspect | Question | | Level 1 | Level 2 | Level 3 |
| Nature of Models | To what extend does your model match with daily life traffic jams? | Description | Model is a copy/ has great similarity | Parts of the model are an exact copy/ Model is a variant or too focused | Model is a hypothetical representation |
| | | Example | -Is completely the same<br>-They match in that they both have cars | -In here, jams form because cars drive a different speed but in real life jams can also form through accidents or traffic lights | N.a.v. |
| Multiple models | Explain why different models could exist that try to explain traffic formation? | Description | Different models have different properties | Different models focus on different aspects | Different models have different assumptions |
| | | Example | -Because then the roads are different.<br>-Some roads have more curves. | -Because with different models, you get different answers<br>-Because there are different kind of jams. | -Because there are different causes of a traffic jam.<br>-Because there are different ideas on traffic jams |
| Purpose of models | Why do scientist use models? | Description | To show the facts | To identify/explain relationships | To examine ideas |
| | | Example | -Because it can help them to imagine how it would look in real life | -To find the cause<br>-To do research | -To test<br>-To experiment |
| Testing of models | How could you test if your model can be used to explain and solve traffic jams? | Description | Test the material/ basic requirements | Compare between original and model | Testing hypothesis |
| | | Example | -To see at what speed they crash | -By driving slowly at the highway<br>-By looking at your model and the real road very carefully | -Build it in real life and then try if it works |
| Changing models | Can you think of a reason why your model has to be adjusted? | Description | To improve it/ When the model does not work | Because it does not match the original | Because of findings from the model experiment |
| | | Example | -Because the road doesn't look nice<br>-Because the cars crash all the time | -Because it is not realistic<br>-The road is not a roundabout in real life | N.a.v |

* This question included an image of another model concerning traffic jams.