# A Germ for Young European Scientists: Drawing-Based Modelling

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**Abstract** An important movement in European science education is that learning should be inquiry-based and represents realistic scientific practice. The inquiry-based nature of science education is essential to interest more young people for a career in science and technology. Creating models is broadly seen as an essential part of those scientific practices. Dynamic models play a central role in science as a main vehicle to express and evaluate our understanding of complex systems. Therefore, the ability to reason with and about models and to create models of dynamic systems is an important higher order thinking skill and as a means to foster the development of scientific attitudes. In teaching children how to model, the choice for model representation is important. Representations can vary from mathematical formula, programming languages and diagrammatic representations. This chapter will present modelling based on drawings, and the SimSketch software with which children can create dynamic, multi-agent models. By representing systems in drawings, assigning behaviour to elements of the drawing and simulate the resulting model, children can express and test their ideas about natural and artificial systems. The chapter discusses conceptual and technical issues related to SimSketch as well as studies in which children have used SimSketch to represent systems such as the solar system, traffic and the spreading of diseases. The role of this approach will be discussed in the context of developments in European educational research.

**Keywords** Simulations · Modeling · Inquiry learning · Scientific literacy

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Y. Cai et al. (eds.), *Simulation and Serious Games for Education*,
Gaming Media and Social Effects, DOI 10.1007/978-981-10-0861-0_2

# 1 Introduction: The Image of Science in Science Education

In Europe, there is an increasing need for students choosing studies and careers in science and technology. Over the years, interest in science has decreased and numbers of students enrolling in scientific and technological studies have been going down. Although in recent years this downfall seems to have come to an end, it is important that the educational system raises interest, skill and motivation for science and technology.

Apart from the need for well-trained scientists, science education also needs to educate for the role in science as part of citizenship education. People need a basic level of knowledge about science in order to function in society, for instance to make choices regarding socio-scientific issues such as vaccination and genetic testing. According to Boerwinkel et al. [1], the scientific knowledge and skills that young people should acquire are

- knowledge and skills regarding concepts in science and mathematics;
- knowledge about the nature of science and mathematics, which includes methodology and foundations; and
- insights into norms and values, both personal and societal.

Together these concepts constitute a basis for empowering citizens in a knowledge society [2]. For instance, for deciding on whether or not to vaccinate their children, people need to know what vaccination is (concept knowledge), know about the value of the claims in favour of and against vaccination (nature of science), have insight into the consequences for themselves and others and associated personal and societal norms and values. Scientific citizenship relates knowledge and insights to a perspective on action that is related to function as a citizen. In this case, the action is making a decision about vaccination. We can therefore define scientific citizenship as the set of knowledge, skills, attitudes and values that contribute to a person's actions as a citizen.

For education in science this means a focus broader than teaching and learning the scientific concepts, by studying not only questions such as *what do we know*? but also *how do we know that*? and *why is it important to know*?

According to leading experts, science education in Europe fails both in making science attractive to young people and in educating science for citizenship. A crucial problem is that science is often taught as a collection of facts and skills to solve problems. For instance, Osborne and Dillon stated in 2008 [3]

> In the past two decades, a consensus has emerged that science should be a compulsory school subject. However, whilst there is agreement that an education in science is important for all school students, there has been little debate about its nature and structure. Rather, curricula have simply evolved from pre-existing forms. Predominantly these curricula have been determined by scientists who perceive school science as a basic preparation for a science degree – in short a route into science. Such curricula focus on the foundational knowledge of the three sciences – biology, chemistry and physics. However, our contention is that such an education does not meet the needs of the majority of students who require a

> broad overview of the major ideas that science offers, how it produces reliable knowledge and the limits to certainty. Second, both the content and pedagogy associated with such curricula are increasingly failing to engage young people with the further study of science. Indeed, there is a strong negative correlation between students' interest in science and their achievement in science tests.

The negative correlation reported by Osborne and Dillon is worrying. Apparently science education is incapable of providing an image of science that is representative of actual scientific practice. Images of scientists as either nerdy, unworldly, or even "evil scientists" are prevailing in popular literature. Bonner [4] states that popular understanding of science suggests that scientific work does not grip the emotions, that it is coldly logical, and that it is not as creative as the actions of the artist. Yet, Bonner argues that much of scientific work is a combination of logical thinking and creative actions such as choosing a subject, finding questions, going against common beliefs, finding solutions, including unorthodox ones, etc. The problem with the "cold, logical" view of science is that it implies to many children that a scientific career is out of their reach, that it is uncreative and perhaps just plain "boring". As a result, talented girls and boys may be diverted from a route toward a career in science.

In the current chapter, an approach to science education for young children will be presented and explored in which young students engage in authentic scientific practice by creating scientific models and simulations. As such this approach is not new. The approach of modelling in education goes back to the 1980s in which time Jon Ogborn pioneered with this approach [5]. Recently, Louca and Zacharia [6] have reviewed the various approaches to modelling in education. We will introduce the basic principles of modelling in science and science education here and argue for the introduction of a more visual and qualitative way of modelling to address younger children. This will be followed by an introduction of SimSketch, our drawing-based modelling tool. The tool will be described as well as some experiences with the tool in educational practice.

## 2 Models in Science and Science Education

In introducing scientific practice to the practice of teaching science, much attention is given to the inquiry cycle [7, 8]. Whereas the inquiry cycle represents relevant processes in scientific inquiry, according to Windschitl and colleagues, a strict interpretation of this cycle may lead to the conception of inquiry as mechanically performing a fixed sequence of steps to test hypothesis, instead of a creative search for models and theories that allow us to form a coherent picture of the natural world [9]. In other words, there is not a single scientific method, but a range of activities that lead to the construction of scientific models.

The philosopher Giere [10] investigated the concept of models as objects that are created by scientists and form a central point in scientific discourse. In this line of reasoning, models are not meant to be a one-to-one representation of reality, but the relation between the model and reality serves a particular purpose in understanding particular features of reality. This has profound consequences for how we see the development of scientific knowledge. The purpose of science is not to discover "laws" that exist in some independent reality, but instead to create models to understand the things we observe. The same models can then help us to predict new observations and be used in the development of new solutions to societal problems. So, instead of being a discipline in which reality is "uncovered" using a fixed method of inductive and deductive steps, science is a *constructive* activity in which models of phenomena are constructed for particular purposes. This also means that multiple models can exist of the same phenomenon, each serving its own particular purpose. In modern science, models are often realised computationally. Astronomers, biologists, chemists and physicists alike use powerful computing techniques to simulate the models they create and use the computational results for predicting states of the world based on their models. For instance, astronomers use advanced simulation models to study the formation of stars and galaxies and to understand the structure of the universe as a whole and biochemists study the working of enzymes in cells using simulations. In science education also, computational modelling using systems such as STELLA [11], NetLogo [12, 13] and StageCast [14] have been designed so that students in secondary education can create models and become acquainted with the principles of scientific computational modelling.

In creating and understanding scientific models, visual representations play a key role in almost all areas of science [15, 16]. Visual representations are used to organize and constrain thought, relate concepts, visualize processes, abstract data and more [17]. In model building, these representations play a role both in *constructing* the model and *evaluating* it, using external data or other means. Especially in the constructive and creative phase, *drawing* is a very useful means of constructing visual representations: drawings allow the construction of representations without a priori constraints and rules of symbolic expression. This helps scientists and students alike to embed creative ideas into their models.

## 3 SimSketch: Creating Drawing-Based Models

This section introduces SimSketch. A more elaborate introduction is given elsewhere [18, 19], therefore only the main features will be highlighted.

### *3.1 Basic Design and Principles*

A model in SimSketch always starts with a drawing of a system or process. For instance a drawing can depict the way energy flows between the sun and the earth [18] or the objects that compose of a mechanical system. The key idea behind

SimSketch is to combine such drawings with a modelling engine, so that the drawings can not only be used to show static structures in the learners' models, but can also become animations visualizing dynamic properties of the model.

In order to do so, the drawing is split into separate objects and each of the objects is assigned a behaviour. A clustering agent supports users in performing this splitting into objects. By guessing which drawing strokes belong together, based on spatial distribution and order of drawing, the clustering agents suggest a division in objects. Users can overrule this division if needed by drawing a grouping stroke around strokes that belong together.

The next step in SimSketch modelling is assigning behaviour to the objects. This behaviour can be an object's independent motion or an interaction with another object. For example, the GO behaviour specifies an object's independent motion in a specified direction, whereas the CIRCLE behaviour specifies that the object moves in a circular orbit around another object. Behaviours can be combined and can interact. For instance, if an object is assigned the CIRCLE behaviour and the object it is to circle around is moving, the circling object will move along too.

Interactive behaviours specify how objects respond to each other. Such behaviours include attractive and repulsive relations between objects. Also objects can "kill" or "eat" other objects. Finally, SimSketch offers behaviours for reproduction and cloning of objects.

After specifying behaviours, users can *run* the model, which creates an animated copy of their drawing in which the objects move according to the behaviours specified. Learners can zoom, speed up, or slow down the simulation and can have the simulation draw traces of the moving objects.

The design of SimSketch is aimed to support essential reasoning processes such as identifying model components, their properties and behaviour in an intuitive way. The object-based nature of the models allows learners to specify one object at a time in a relatively simple way, whereas complex behaviour may result from the combination of object and behaviours. SimSketch focuses on domains in which modelling results are best represented through animations, displaying qualitative aspects of complex behaviour. Two of these domains are elaborated below.

## *3.2 Modelling the Solar System*

The first model investigated using SimSketch is that of the solar system. This model represents the movements of the planets around the sun. The drawing that forms the basis of the model displays the sun, some planets and, at least, the moon. Each of the objects, planets, moon and sun is labelled, as displayed in Fig. 1a. All planets receive the CIRCLE behaviour that instructs them to move around the sun. The moon also gets the CIRCLE behaviour with the instruction to move around the earth.

In this way, a *phenomenological* model of the solar system is created. The fact that the planetary orbits are in fact ellipses is neglected and no cause or explanation for the circular movement is given in this model. Also, no collision detection occurs

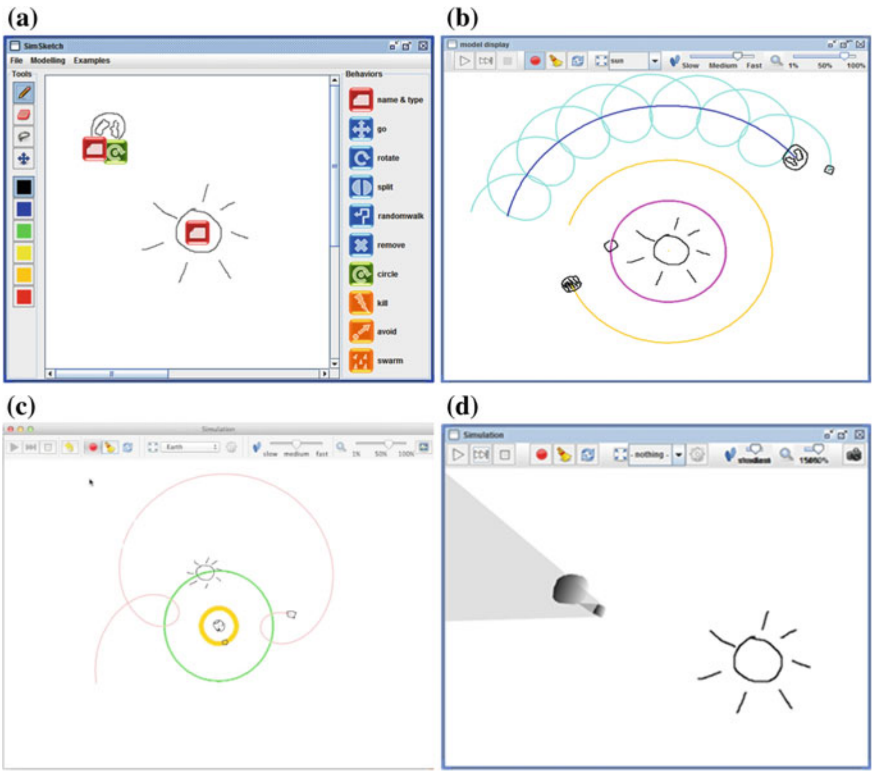


**Fig. 1** Modelling the solar system in SimSketch. **a** *Top left* drawing the model. The "stickers" on the drawn elements specify the behaviour of each of the elements. **b** *Top right* simulating the model. Each of the moving planets leaves a trace as they move over the screen. **c** *Bottom left* by centering the earth instead of the sun the loops in the trajectory of Mars can be used to understand its retrograde movement. **d** *Bottom right* SimSketch allows indicating elements as light sources and light blockers, allowing to show the occurrence of eclipses

in this model—planets follow their orbits as specified. Still the model can be used to reveal several interesting properties of the solar system.

The first is the shape of the trajectories of satellites such as the moon. As is visible from Fig. 1b, the moon displays a cycloid orbit as seen from the sun. Moreover, by centering one of the planets, it can be made clear that the relative motion of the earth and the other planets may give rise to certain phenomena on the earthly sky. For instance, outer planets (those outside earth's orbit) display retrograde movement. If the position of—for instance—Mars on the sky is followed over the year, one notices that it will move from right to left most of the time, but in certain periods it will move in the opposite direction, the so-called retrograde movement. During retrograde, Mars also shines brighter at the evening sky. By fixing the position of the earth in the simulation and displaying Mars' orbit one can see the loops in Mars' orbit relative to the earth that explain this phenomenon as can be seen from Fig. 1c.

By adding light rays and shadows to the simulation, SimSketch can also explain the occurrence of solar and lunar eclipses (Fig. 1d). Here a limitation of the 2D nature of the model becomes apparent: explaining solar eclipses in this way should lead to an eclipse every month. In order to explain that this is not the case, a 3D perspective is necessary. Nevertheless, these examples show that the phenomenological model of the solar system that can be constructed in SimSketch has the power to explain relatively complex phenomena.

## *3.3 Modelling Multi-agent Systems: Traffic*

As an illustration of multi-agent modelling we introduce traffic, and more specifically the spontaneous formation of congestions without an apparent cause. In cases of high traffic density, sometimes congestions occur spontaneously, without the presence of a clear cause, such as an accident or crossing.

In modelling such a system, two aspects are important in the model. One is that, even if all drivers intend to drive at the same speed, it is impossible to maintain *exactly* the same speed for all. The second is that drivers brake to avoid collisions with the car in front of them.

In SimSketch a traffic system can be constructed by drawing objects representing cars and an object that represents a circular road. Cars receive the behaviour to drive along the road with a give speed. In order to avoid having to draw many cars, a *factory* behaviour is associated to a single car object. This factory turns the car into a prototype of car objects that will be produced by the simulation. Apart from saving on drawing time, this also allows for experimentation with traffic density, by adjusting the number of cars that should be produced.

Figure 2 displays the model. Figure 2a displays the model as drawn, Fig. 2b shows the resulting simulation. Without extra measures, the simulation would result

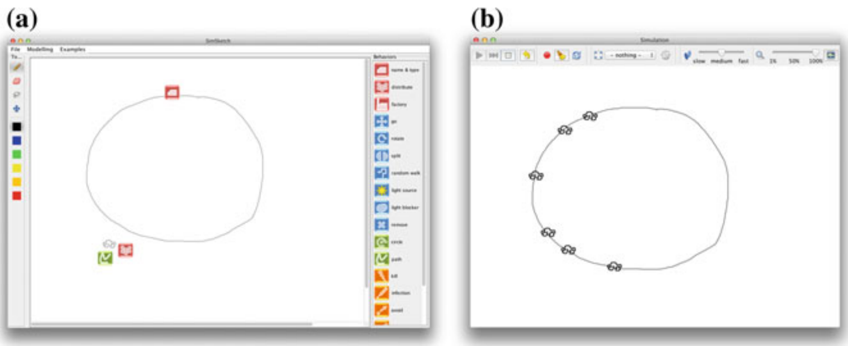


**Fig. 2** Modelling traffic and congestions in SimSketch. **a** *Left* the drawn model, with as special element the factory that produces a specific number of cars. **b** *Right* the simulation with the cars moving around the drawn road displaying the spontaneous appearance of congestions

in cars moving around the road without any congestion, all with exactly the same speed. In order to display realistic behaviour, the factory can be adapted in such a way that a small randomization on the parameters (in this case speed) is applied to the objects produced. This has as result that the cars have slightly different speeds, and hence will collide. A second measure, making the cars adjust their speed to objects in front of them provides the observed behaviour.

Again, this model is phenomenological. There is no explanation of why the cars behave the way they do. This is both a limitation and strength of the model. The limitation relates to the explanatory power of the model, the strength is that it shows that with only a small number of assumptions, a rather complex phenomenon can be understood using the model. In designing learning activities around this model, such strengths and weaknesses should be addressed.

## 4 Experiences with SimSketch

SimSketch has been used in educational practice, within and outside school contexts. In this section, three practical uses of SimSketch are presented to display the range of application of the drawing-based modelling approach.

### *4.1 Master Classes*

Many schools in the Netherlands nowadays sustain honours programs for their successful students. Within the context of these honours programs, the University of Twente offered master classes for eighth grade honours students. Six male eighth grade students aged 14 participated in a master class on modelling. The topic of the master class was scientific modelling and consisted of three 3-h sessions. In the first session the concept of modelling was introduced using two examples: weather models and models of the economy. Also a system dynamics [20, 21] model was created collaboratively of income and spending in the context of saving money for an iPad. Finally SimSketch was introduced. Participants received a homework assignment to practice with SimSketch and think of a topic for a modelling project. In the second session (one week later), participants presented their modelling plan that was discussed in the whole group. Chosen topics were traffic (two times), the spreading of the plague in medieval Europe, the python population in the everglades, the influence of alcohol on the brain and the management of large crowds. Most plans were elaborations of suggestions given in the homework assignment. Plans were discussed, resulting in more elaborated plans as well as requirements for new features in the software. For instance, the two students that chose traffic requested a behaviour that generated multiple instances of drawn objects that resulted in the factory behaviour (see Sect. 3.3). These new features were implemented in the days following the session. In the final session, students completed their models using the new features, and presented them to the group. In the presentations they were asked to justify the way the model had been built and why it could be a good model of reality.

Prior to the first session and at the end of the third session, participants filled in a questionnaire on the nature of models and their own stance toward science. The nature of models questionnaire consisted of open questions, for instance on how models should be tested. The opinion about science was measured using 4-point Likert scale questions, such as “I like to discover new things”. The final questionnaire also contained questions for evaluating the software using a 5-point Likert scale, containing questions such as: “I would like to work with SimSketch again” and “SimSketch is easy to learn”. Moreover the models created by the learners were collected in their increasing versions. During all three session observational notes were taken.

All participants created models that could be simulated and for which they indicated that they represented their ideas. These simulations showed behaviour that expressed at least one core idea, for instance the way populations fluctuate in a predator-prey system. One participant decided not to use SimSketch but instead used a demo version of a professional traffic simulator to show the effect of road works on traffic flow. As the teachers of the master class found it more important that students caught the purpose of modelling than to promote SimSketch they allowed this student to use this software that he had downloaded from the Internet.

On the questionnaire that evaluated SimSketch, participants evaluated SimSketch positively (mean value 3.81 on a five point scale, with 3 as neutral value).

In participants’ views on science a remarkable change occurred. In the pretest the main view on models was that of scale models, which was mentioned by five of the six participants. Also five participants stressed that models should be as precise as possible to be a representation of reality and that not everything could be modelled. No participant mentioned models for reasoning or simulation. In the post-test, participants all mentioned reasoning and simulation, and stressed that almost everything can be subject of modelling. Also, they mentioned modelling of *ideas,* and that there can be multiple models of reality depending on the purpose of the model.

Despite the fact that the number of participants was small, and these honours students were certainly not average students, the study does reveal interesting aspects of model-based reasoning in teaching. The first was the ability of students to develop their own topic and a coherent model of that topic. They could do this without programming experience. SimSketch proved to be easy to learn, which was confirmed by the evaluation questions. Although the students initially did follow suggestions, after that all students had gathered documentation and related that to model elements. All students placed their model in a context—that was not given. For instance the predator-prey system was placed in the context of the python plague in the everglades and crowd management was placed in the context of a recent item in the news on panic in a big crowd.

Due to the small group, we had the opportunity to adapt the system to the needs in their individual model proposals. This contributed to the development of the

SimSketch system in such a way that the new features were developed on demand in the models created by the learners. Although not scalable, this method proves valuable for the development of advanced educational software and contributed to the engagement of the participants—as they could and did suggest elements of the new version of the program.

## 4.2 Solar and Lunar Eclipses

In a study to investigate whether young children (from age 7) are able to use SimSketch we designed a modelling task on the solar system. The main goal was to understand and explain the occurrence of solar and lunar eclipses. This task was offered to children visiting the NEMO science center in Amsterdam. They used SimSketch to create models of the solar system and were specifically asked to create situations in which solar and lunar eclipses occur.

247 participants (127 girls and 121 boys) in the age range of 7–15 participated. Participants filled in an 8-item multiple-choice test on their knowledge of the solar system that was specifically designed for this task. Questions included "What composes the solar system?" and "What happens at a solar eclipse?". They then received a short SimSketch tutorial. After that they created a model drawing of the solar system.

In the instruction they were asked to create an animated view of the solar system, including the light and shadow behaviours as depicted in Fig. 1d, and to stop and save the simulation at the moment a solar or lunar eclipse would occur. Participants filled in the domain knowledge post-test. Drawings were scored on the presence of essential elements in the representation of the solar system and relations between them. Data were analyzed to search for relations between age, gender and prior knowledge score, drawing score and post-test score. The main question was whether students would gain knowledge from this short modelling activity, whether the quality of the drawing contributed to their knowledge gain, and whether such results were dependent on age and gender.

Detailed results of this study are published elsewhere [22]. Here we summarize the main outcomes. On average, students worked on the task for approximately 40 min, including pre- and post-tests. This was the maximum that is realistic in the museum context. For instance, the parents of 15 of the children wanted to move on before completion of the task by their children. For these children the dataset was incomplete. These data were excluded from analysis.

Because no explicit instruction about the domain was given in this study, any knowledge gain between pre- and post-test should be attributed to the activity on the task performed by the children. Therefore, a large knowledge gain was not to be expected. The main scores on pretest and post-test are depicted in Fig. 3. Analysis of the pre- and post-test data revealed that there was a small but significant increase in score, from pre- to post-test. Detailed analysis showed that this increase could mainly be ascribed to the young students, between 7 and 9 years old. Older students

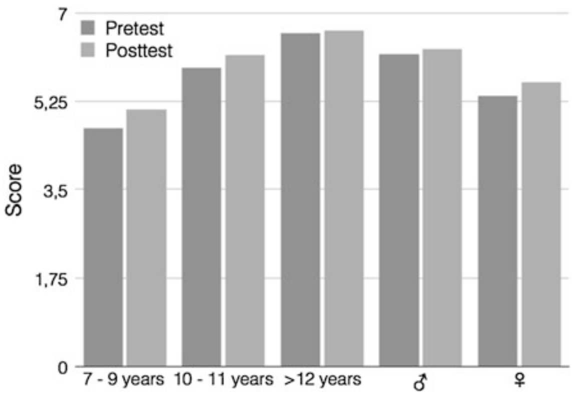


**Fig. 3** Pretest and post-test scores, split for age groups and gender, indicated by ♂ and ♀. Maximum score is 8

scored higher on both pre- and post-test, but gained less than the youngest group, probably due to a ceiling effect. Also it was found that girls gained significantly between pre- and post-test whereas boys did not. To investigate whether the drawing contributes to knowledge acquisition, we computed a partial correlation between post-test score and model score with pretest score partialled out. This correlation turned out to be significant ($r$ (222) = 0.186, $p$ = 0.005), indicating an influence of the drawing process on knowledge acquisition by the participants. Better drawings were associated with higher gains on the post-test. Further analysis of the data, using structural equation modelling showed that models with and without the quality of the drawing included fitted almost equally well on the data. Therefore we should see the relation between the quality of the model, as expressed in the number of elements included, with the learning gain as undecided and an issue for further study.

The results from the motivational scales and the participants' responses on the open question indicate the potential of the approach to motivate children to learn by engaging them into drawing-based modelling. Scores on how participants evaluated SimSketch, the perceived competence (the amount to which participants thought they could use SimSketch for the task) and valuing (the extent to which they thought that the task as a whole was interesting and attractive) were above average. Competency scored 2.98 and valuing scored 2.91, both on a scale from 1 to 4 with 2.5 as neutral value.

These results show that young children are capable of creating drawing-based models. Their model scores—in the range of 6.5–8.5 (max. 14)—indicate that they have included the major essential elements in the drawing, but omitted relatively unimportant details. Children from 12 years old and above display enough understanding of the solar system to create accurate models. Knowledge gains can be seen in younger groups, especially for girls. Summarizing, we see that drawing-based modelling is a feasible approach to learning scientific topics, within reach of even young children, and that it potentially contributes to the resolution of misconceptions in astronomy [23].

## 4.3 Lesson Design for Drawing-Based Modelling

In this section, we describe a first implementation of SimSketch in regular lessons in primary education as an example of how a modelling lesson may be designed. The lesson as described has been performed multiple times in sixth grade of a primary school in the Netherlands.

The lesson focuses on the principle of modelling and builds on the traffic model as described in the previous section. After a short introduction on the basic ideas of modelling and the role models play in science (using weather models as an example) students were asked if they knew situations where congestions seem to appear without apparent cause, for instance when driving with their parents. After a brief discussion, a short movie was shown in which cars drive on a circular road and in which spontaneous congestions occur.

Students were asked to think of possible causes of such traffic jams. As part of this process, they were asked to walk in a circle through the classroom while maintaining a constant speed (see Fig. 4). This experience was discussed. The main question in the discussion was whether students felt they could move freely and if not what caused any hindrance. Many students mentioned causes such as reaction time, inattentive drivers, etc. as causes of the traffic jam. In further and deeper discussion of these causes the teacher tries to reach consensus on two factors: cars

**Fig. 4** Children playing out the traffic situation by walking around and assuming the role of cars

never drive at exactly the same speed and drivers want to avoid collision. Factors such as reaction time and braking are related to the variables speed and the tendency to avoid collisions.

The teacher then developed the model by drawing on an interactive whiteboard, asking students about what the model elements should be. After doing this, the teacher drew the elements on the board and explored the influence of the various behaviours assigned, such as the variation in speed.

When the model showed the behaviour that was observed in the movie, a class discussion followed in which the essential properties of the model were discussed. Three questions are central in this discussion: "Does the model explain the phenomenon?", "How does the model explain the phenomenon?" and "What are the limitations of the model?".

These three questions are essential in understanding the functions of this particular model and the role models play in understanding scientific phenomena. Therefore these three questions should be part of any lesson plan that involves drawing-based modelling, regardless whether the models are created class-wise (such as in the case described) or individually by the students.

Only informal observations are available from the lessons that were performed with this lesson plan. In all lessons, the class came up with the essential elements for the model after walking through the class. Also in the final discussion, the students were able to indicate the limitations and possible extensions of the model. This shows the value of the final class discussion in which students are stimulated to reflect on the role of the model in understanding the modelled system.

## 5 Conclusions

The drawing-based modelling approach as introduced in this chapter aims to engage students in genuine scientific activities in which models are created. The approach shows that scientific activities can be challenging and creative. Compared with other approaches to modelling such as those based on coding such as NetLogo [13], or writing equations [11], drawing-based modelling aims at making modelling available for younger children. The development of the SimSketch software is still a work in progress and therefore the results presented here must be considered to be tentative.

Comparing the three cases that were discussed in the previous section, we see that the contexts in which SimSketch was applied vary. The master class students received quite intensive support on their modelling processes, which took place in the context of a really open task. This way of working with students lead to deep thinking about the models that were created and the co-creation of new behaviours in SimSketch. In the new version of SimSketch it will be possible to create new behaviours by writing code, an option that will be available in an "advanced" mode. Adding this option would lead to the possibility of real open-ended modelling, not restricted by the set of available behaviours. In order to make it possible, a library of functions is under construction that would serve as the basis for coding behaviour.

The other two examples are less open ended. Learners were asked to model a specific, given phenomenon. From these examples we can glean that learners are capable of creating models based on a relatively simple instructions and a limited set of behaviours. The collaborative creation of a SimSketch model on traffic is a proof of concept of modelling lessons in which the role of models is introduced and discussed. The main difference between the two situations with respect to the learning goal is the role of the model and phenomenon. In the NEMO study the goal focussed on understanding the domain, the solar system, whereas in the traffic study, modelling itself was in focus. In both cases, drawing-based modelling has a role, but the goals are essentially different. This explains the focus on discussing the role of the model in the traffic study.

On the motivational side, all students indicated they liked working with SimSketch. Whereas this is by no means an indication that they developed a more positive attitude toward science, at least it is a start. The shift in thinking about models by the students in the master class toward a different view on the meaning of models and their function shows that it is possible to reach such a change through working on a modelling task. This makes the master class a proof of concept of the basic ideas of drawing-based modelling as driving force behind the development of scientific attitudes. Of course a single intervention such as the master class or even the single lessons on traffic is not enough to have permanent effect. Science curricula for upper primary and lower secondary grades should include multiple modelling experiences to result in a lasting effect. In order to accomplish this, studies into the conceptualization and actual levels of scientific understanding and attitudes in young students, as well as teacher training programs for school teachers, are necessary [24].

## *5.1 Future Developments: Creating Scientific Practices on Drawing-Based Modelling*

Apart from including more encounters with drawing-based modelling, also improvements in the lesson design are needed, as well as further development of the software. Lesson designs should aim at creating genuine scientific practice within science lessons, with a goal that children see a role for themselves within science. Engaging students this way can turn around the image of science as only deductive and uncreative. Genuine scientific practice includes connection to actual scientific research. In order to achieve this, we are currently developing lessons in collaboration with university researchers. For instance, in collaboration with Naturalis, a museum on natural history, we develop an application for the simulation of evolutionary processes, in which students can create models to explain the evolution of the colours of garden snails. They use data sets made available by a Naturalis researcher to investigate the distribution of the different-coloured snails and then create models simulating the evolution of snails under the selection pressure of birds predating on the snails.

Another development is the introduction of the third dimension in the software. Although drawing is easiest done in two dimensions, some systems to be modelled are intrinsically 3D. For instance in the case of the planetary system, the third dimension is needed to understand that eclipses do not occur every month. Another example is 3D-interaction of molecules based on the spatial distribution of atoms in the molecule. For this, the idea is for students to create the drawing-based model on a 2D canvas and then simulate the model in three dimensions by linking it to a 3D virtual environment. This will allow students to explore more complex systems in a more realistic way.

In conclusion, the results from the present studies show that drawing-based modelling provides a promising approach to engaging young students in science, and to turn around their opinion to see science as a creative enterprise.

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