Chapter 8
Drawing-Based Modeling in Teaching Elementary Biology as a Diagnostic Tool

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8.1 Introduction and Theoretical Background

An important goal of science education is to acquaint students with the goals and methods of science, including the roles and functions of models. According to several authors (DeBoer, 2000; Longbottom & Butler, 1998), not only must students learn the facts of science, but they must also learn *about* science. Students should adopt scientific thinking characteristics such as open-minded and critical thinking, problem solving, an understanding of the relation between theory and evidence, and hence, an understanding of the nature of scientific knowledge (Kuhn & Pearsall, 2000; Longbottom & Butler, 1998). As discussed in section A in this book and in other literature, modeling is an important element of such scientific reasoning, and modeling competence is the basis of science education (Louca & Zacharia, 2012; Magnani, Nersessian, & Thagard, 2012; Windschitl, Thompson, & Braaten, 2008).

When modeling is brought to the classroom, students can develop a scientific view on the world and engage in scientific thinking (Zimmerman, 2007). Science education should explicitly address the acquisition of these higher order skills so that students can develop the scientific literacy needed to be able to function as citizens in modern society. Such skills and literacy are generally considered to be part of the set of "21st century skills," even though there are many versions of what these skills entail (e.g. McComas, 2014).

Models play the role of objects that represent the relation between reasoning and reality. In science education, models can be used to explain scientific phenomena (e.g. as pictures or animations to display how enzymes work), as an object of study (e.g. using a computer simulation), and as objects that can be constructed and

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modified by students (de Jong & van Joolingen, 2008; Grosslight, Unger, Jay, & Smith, 1991).

Modeling in science education is often implemented as computer-based modeling in which students create executable models by writing programming code (Blikstein, Abrahamson, & Wilensky, 2005; Brady, Holbert, Soylu, Novak, & Wilensky, 2015) or differential or difference equations (Neves, Neves, & Teodoro, 2013; Teodoro & Neves, 2011), which are often supported by graphical representations that are based on system dynamics (Doerr, 1996; Milrad, 2002). For younger children who lack the language needed to understand code or equations, such modeling tools are out of reach, but other ways to specify computational models are possible. In the approach described in this chapter, *annotated drawings* are used to specify the behavior of the model. Drawings have been used to express and communicate knowledge in science education (Ainsworth, Prain, & Tytler, 2011), and in our context, drawings are used as the basis for the modeling program SimSketch (Bollen & van Joolingen, 2013; van Joolingen, Aukes, Gijlers, & Bollen, 2015). In this approach, students create drawings of scientific phenomena and, using the language of icons representing system behavior, convert these drawings into computational models. Furthermore, drawing-based modeling is very useful for early science education because drawing enables children to turn their spontaneous thoughts into more scientific concepts (Brooks, 2009).

In the current chapter, we investigate how teachers can integrate drawing-based modeling into their classroom practice and how the development of students' scientific reasoning can be diagnosed as a result of having them engage in drawing-based modeling with SimSketch. We provide a short introduction to scientific and model-based reasoning before discussing the method and results of our study.

8.1.1 Scientific Thinking and Modeling Competence

Scientific thinking skills are required to link empirical evidence to theoretical considerations (Kuhn, Amsel, & O'Loughlin, 1988). Zimmerman (2007) reviewed many studies that have been conducted on this subject. He then explained that scientific thinking is:

> *...the application of the methods or principles of scientific inquiry to reasoning or problem-solving situations, and involves the skills implicated in generating, testing and revising theories, and in the case of fully developed skills, to reflect on the process of knowledge acquisition and change (p. 173).*

Modeling involves these aspects of generating, testing, and revising theories because models can be seen as theoretical representations of phenomena. Scientific knowledge is a complex and dynamic network of models. Models are used to test hypotheses and describe scientific phenomena. Learning goals for modeling are related to the subject matter taught, to learning to model, and to the role of models in science. In modeling, students learn to discuss and criticize their thoughts about their model and to reflect on their model (Louca, Zacharia, & Constantinou, 2011). Modeling in science classes often takes the form of *computer-based* modeling. Using software tools such as Co-Lab (Van Joolingen et al., 2005) or NetLogo (Wilensky & Reisman, 2006), students create computer models of the phenomena they are investigating. If students learn to model at a young age, using relatively simple phenomena, we assume that this will be beneficial for their modeling education in later years, involving more complex scientific phenomena. Earlier research and reviews about learning by modeling have identified two reasons for why modeling has not gained ground in early education: the lack of tools and educational materials and teachers' lack of experience with using models for learning (Louca & Zacharia, 2012, 2014; Louca et al., 2011).

Drawing-based modeling is aimed at addressing these reasons by providing an easily accessible tool, *SimSketch* (Fig. 8.1), for teachers and students, without the need for more advanced modeling skills (Bollen & van Joolingen, 2013). In earlier studies, it was shown that learners from the age of 10 years old were capable of creating computational models in the domains of astronomy (van Joolingen, Aukes, Gijlers, & Bollen, 2015) and evolution (Heijnes, van Joolingen, & Leenaars, 2018). In the current study, we integrated this tool into a series of lessons and investigated how it functions in building modeling competence. In the lessons, students learn to create their own representation of a scientific concept, while finding out which resources will be relevant and reliable when used in their models. Drawing allows them to deal with different representations of the same scientific concept, which ensures creative reasoning (Ainsworth et al., 2011). Modeling with SimSketch takes the form of assigning behaviors to the elements of a drawing. For instance, in a model of evolution, the behavior of "reproducing" can be assigned to a drawn animal, resulting in offspring with a slightly mutated color. Predators can hunt and eat

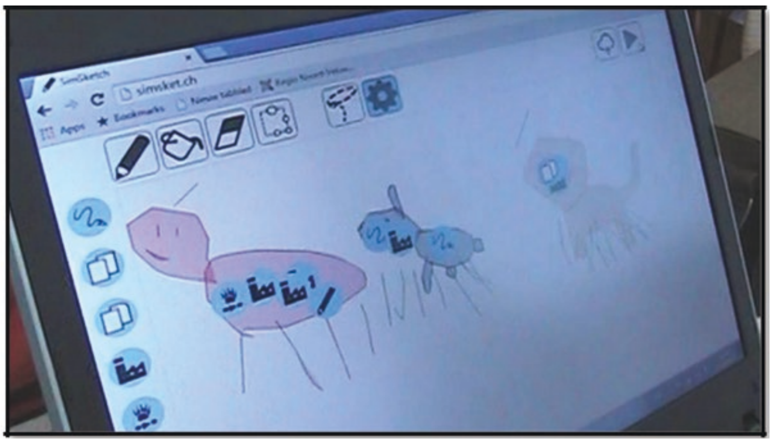

Fig. 8.1 Drawings in SimSketch of Dyad A during the practice lesson. In the online modeling and drawing tool SimSketch, different behaviors (e.g. reproduction, mutation, and hunting behavior) can be given to the objects

animals when they have been assigned the "hunting" behavior. Creating this representation is modeling in itself, but SimSketch adds the executable nature of a model, allowing for a quick cycle of constructing, evaluating, and revising activities that are closely connected to scientific thinking and the aspects of modeling competence. In this way, drawing-based modeling is a real scientific activity that may contribute to scientific thinking.

8.1.2 Assessing the Understanding of Models

Earlier research found that modeling can contribute to a better understanding of the nature of science (Louca et al., 2011; Sins, Savelsbergh, van Joolingen, & van Hout-Wolters, 2009b; Chap. 4). This in turn may lead to more proficient scientific thinking because modeling is an important part of scientists' work. When students learn more about modeling, they also gain more insights into the approach that scientists use. In this study, the level of understanding of models is used as an indicator of a shift in students' thoughts about the nature of science. Grünkorn, Upmeier zu Belzen, and Krüger (2014) developed a framework for assessing students' understanding of scientific models (Chap. 1). They used five categories: *nature of models*, *multiple models*, *purpose of models*, *testing models,* and *changing models*, reflecting both the epistemological aspects of models as representing scientific knowledge and the roles of models in science, including their relations with empirical evidence. Both aspects are important as the roles link models with scientific reasoning, and the epistemological aspects stress epistemological understanding, which influences students' cognitive processing on a modeling task (Sins et al., 2009b).

The aim of this study is to gain insight into the opportunities for using drawing-based modeling for teaching, learning, and assessment in science education, integrated in a classroom environment. The main research question is:

How can drawing-based modeling be used in a science education classroom to develop and assess students' modeling competence?

We focused on two specific aspects of modeling competence: (a) students' understanding of models and (b) the ways in which students' reasoning processes can be indicators of their modeling competence. The main question was divided into three partial questions:

1. How can we extract students' modeling competence from their behavior in creating SimSketch models?
2. How does drawing-based modeling change students' understanding of models?
3. How is student reasoning about drawing-based models related to their modeling competence?

As part of a design-based study design, we developed a series of lessons with the topic of the evolution of snails, with a target audience of ninth-grade students (14–15 year olds) in general secondary education. In order to address the link between empirical data and theory, we established a link with a large European science project. In four lessons, students learned to use the modeling tool, collected data, created models for explaining the data, and reflected on the modeling process. We expected this lesson series to result in students' deeper understanding of scientific reasoning and the nature and use of models.

8.2 Method

In the *design* phase of this study, learning goals were elaborated, and the lessons were designed in collaboration with teachers and domain experts. In the *implementation* phase, the lessons were taught in seven ninth-grade classes. Process and outcome measures were collected in order to assess students' modeling competence.

8.2.1 Design

The students learned to understand modeling in the context of the evolution of snails. Prior to the lesson series, students had acquired knowledge about evolution as part of their regular teaching program. The lesson series focused on the construction of models showing the dynamics of evolutionary processes.

The lesson series was developed in cooperation with Naturalis Biodiversity Centre in Leiden, the Netherlands. Naturalis participates in "The Evolution MegaLab," a European citizen science project designed by the Open University in the United Kingdom in 2009 (Worthington et al., 2012). On the website of the Evolution MegaLab, the color polymorphism of the snails is explained, and observations of the shell color, banding, and environment can be studied. Participants can also collect their own data by finding snails in their environment and can add their data to the database. An expert group was formed to discuss the contents of the lesson series. This expert group consisted of two experienced employees of Naturalis from the department "Educational development" as well as the first two authors of this chapter.

The lesson series was designed to achieve four learning goals related to the development of modeling competence. These goals were supposed to be met at the end of the lesson series:

1. The students are able to relate a model to the real situation (understanding the nature of models).
2. The students are able to evaluate the model they created (testing and changing models).
3. The students are aware of the fact that a model is not a copy of reality (understanding the nature of models as well as testing and changing them).

4. The students recognize similarities between their own method of working and the way scientists use models in their work (understanding the nature and purpose of models).

To summarize, these learning goals are related to modeling competence as described in Chap. 1, especially to understanding the *nature* of modeling (on levels II and III, learning goals 1 and 3) and to *testing* and *changing* models in relation to their purpose (on levels II and III, learning goals 2 and 3).

The lesson series consisted of four lessons, and separate learning goals were formulated for each lesson. The general construction of the lesson series was:

- Lesson 1: Introduction to modeling and practicing with SimSketch
- Lesson 2: Collecting data in the field about the evolution of the snail
- Lesson 3: Modeling the evolution of the snail with SimSketch
- Lesson 4: Reflecting on models and their connection to science

The lessons were adjusted to the test school, where each lesson took 45 min. The first versions of two of the four lessons (lessons 1 and 3) were given in a grade 10 class with 21 students. These two lessons included the most innovative aspect of the series: using SimSketch to create computational models. After the pilot, the lesson series was adapted on the basis of the students' and teacher's experiences.

8.2.2 Participants

Seven ninth-grade classes from one secondary school with a total of 204 students participated in this study. The classes belonged to two levels of general secondary education, four classes were part of "higher General education" (marked G below), and three classes were "Preparatory higher education" (marked P below). These classes were taught by three different teachers. An overview can be found in Fig. 8.2. Participation was obligatory for all students, and the exercises in their student man-

Teacher	Class	Number of students	Complete sets of modeling questions
1	G1	32	20
	G2	32	25
2	G3	29	10
	G4	29	10
	P1	28	17
	P2	28	8
3	P3	26	20
Total:	7 classes	204 students	110 sets

Fig. 8.2 Overview of the teachers, classes, number of students, complete sets of modeling questions on pre- and post-tests, and the videotaped dyads

ual were graded. Unfortunately, due to practical circumstances, only about half of the data sets were completed (Fig. 8.2). None of the students had previous experience with drawing-based modeling or with any other kind of computer-based modeling. We deleted the pre- and post-tests of students who did not finish, did not fill in the answers seriously, or submitted unreadable answers due to bad handwriting.

8.2.3 Conditions

In all lessons, the students worked in pairs or triplets. The conditions of the fieldwork differed between the classes. Five worked during a week with cold nights. Two classes went to the field a week later because it was damper and warmer outside, and there were probably more snails. In the final lesson, a Skype session with a scientist from Naturalis was planned to help students make the connection between models and their use in science. Four classes actually engaged in this session. The students in the other three classes were able to ask questions of the first author of this chapter, who was present at every lesson.

8.3 Data Collection and Analysis

8.3.1 Change in Students' Understanding of Models

We examined the effect of the lesson series on students' understanding of models using a pre- and post-test design. Eight open questions on the tests asked about students' understanding of models, thus modeling competence. These questions were used in a questionnaire from a previous study about the relation between students' epistemological understanding of computer models and their cognitive processing on a modeling task (Sins, Savelsbergh, van Joolingen, & van Hout-Wolters, 2009a). There were two questions each concerning the aspects of modeling competence (Fig. 1.3) except changing models. Questions addressed general modeling features such as "What is a model in your opinion? (nature)" and "Why do scientists use models? (purpose)" and also included reactions to statements such as "Scientists need to test their models (testing models)" and "It is impossible to determine which model is the best (multiple models)."

We developed a scoring system for these eight questions on the basis of the revised framework for students' understanding of models and their use in science, including levels of complexity and their categories (Grünkorn et al., 2014). In general, a level 1 understanding implies that students see models as simple copies of reality. At level 2, students realize that there are specific choices that they need to make to arrive at a suitable scientific model and that a model is a possible variant of reality. At level 3, students understand that models can be used to test hypotheses and that the modeler plays an active role in the modeling process (Grosslight et al., 1991; Grünkorn et al., 2014; Sins et al., 2009a). We examined whether there was a shift in students' understanding between the pre-test and post-test. Indications of this shift would be a shift from modeling competence levels 1 and 2 to level 3, which is a shift from seeing models as media to seeing models as a research tool.

8.3.2 Scientific Reasoning

In addition to the quantitative data, we videotaped two pairs of students during the two lessons in which they worked with SimSketch in order to gain insights into their reasoning with the models and modeling tool. Video transcripts were analyzed for statements about scientific reasoning, and the SimSketch drawings students made were used to support our findings from the evaluation of students' scientific reasoning processes.

8.4 Results

In this section, we combine quantitative data from the pre- and post-tests with a qualitative analysis of the statements students made, their answers on the exercises, and the models they drew.

8.4.1 Understanding of Models

A change in students' understanding of models was tested by a statistical analysis of the pre- and post-tests the students ($N = 110$) had to fill out. Descriptive statistics of the test scores of all students can be found in Fig. 8.3, such as the test scores of subgroups consisting of G and P students.

			Total test score		
	Students	N	M (SD)	Median	95 % CI
Pre	All	110	6.92 (2.15)	7.0	[6.51, 7.32]
Post	All	110	8.32 (2.38)	8.5	[7.87, 8.77]
Pre	G	65	6.56 (2.34)	6.0	[5.85, 7.26]
Post	G	65	7.53 (2.32)	8.0	[6.84, 8.23]
Pre	P	45	7.47 (1.77)	8.0	[6.94, 8.00]
Post	P	45	9.42 (2.20)	9.0	[8.76, 10.08]

Fig. 8.3 Means, standard deviations, and confidence intervals for the total test scores of all students together, the G students, and the P students (*Note.* The maximum score of a test is 24)

8.4.2 The Progress of All Students

Because students' test scores were not normally distributed, a Wilcoxon signed-ranks test was used. The output indicated that the median post-test scores were statistically significantly higher than the median pre-test scores ($Z = 5.43$, $p < 0.001$). Cohen's d, a measure of effect size, ($d = 0.62$) suggested a medium effect, although the final level could not be considered very high.

8.4.3 Difference Between G and P Students

As expected, Mann Whitney U tests showed higher pre-test scores for P students than for G students ($U = 1022.00$, $p = 0.007$). However, the effect size ($d = 0.45$) suggested a small effect. On the post-test, a similar difference was found: ($U = 797.50$, $p < 0.001$). In this case, the effect size ($d = 0.83$) suggested a large effect. Separate Wilcoxon signed-ranks tests for the P and G groups showed a small gain for G students ($Z = 3.16$, $p = 0.002$, Cohen's $d = 0.44$) and a large effect for P students ($Z = 4.55$, $p < 0.001$, $d = 0.99$).

8.4.4 Progress per Aspects of Modeling Competence

The answers to the questions on the pre- and post-test with an open format were qualitatively categorized into the four aspects of the framework for modeling competence (Fig. 8.4).

Wilcoxon signed-ranks tests show that students scored significantly higher on questions on the post-test on the nature of models ($d = 0.74$) and multiple models ($d = 0.28$) than they did on the pre-test. No significant differences were found for the purpose of models and model testing.

				Wilcoxon signed-ranks test	
Aspect	n	Mdn pre-test	Mdn post-test	Z	p
Natureof models	110	2.00	3.00	5.47	< .001
Multiple models	110	1.00	2.00	2.28	.023
Purposeof models	110	2.00	2.00	1.76	.079
Testing models	110	2.00	2.00	.88	.380

Fig. 8.4 Medians for the test scores for the different aspects and output from the Wilcoxon signed-ranks test

8.4.5 *Scientific Reasoning Process*

Two pairs of students were videotaped during the first and the third lessons. During the first lesson, we could see how they practiced with SimSketch, and during the third lesson, we could see what elements of the model they drew, what they discussed about the model, and the amount of help they needed. In this section, we report the results of the analyses about statements, drawings, and exercises for these two dyads on the different levels of scientific reasoning (Fig. 8.4).

8.4.5.1 Dyad A: Class G1

In the first lesson, this dyad tried all the buttons available in SimSketch. For example, they drew a rabbit and a lion and gave them all kind of behaviors (Fig. 8.1).

In the third lesson, student 1 of this dyad took the lead. A few statements made by this student in this discussion can be read below. Student 2 did not respond and was distracted most of the time. All quotes were translated from Dutch into English.

Student 1: "How can the snails suddenly have other colors?" (1.26 min.) […]
Student 1: "All kinds of new species originated." (2.12 min.) […]
Student 1: "They adapt to their environment, I like that." (3.35 min.) […]
Student 1: "Miss, what should we do now?" (5.44 min.)
Teacher: "You need to create a background, like a big colored surface, which is the forest." […]
Student 1: "We need to draw a yellow and a brown or pink snail." (8.38 min.)
Student 1: "Wow! New species originated." (13.26 min.) […]
Teacher: "It looks good, but what is missing from your drawing?" (14.50 min.)
Student 1: "A background and a bird."

The student's and teacher's discussion consisted of four subtopics. The student made two observations and had one idea of his own. The student did not elaborate on his observations. The student said that the snails adapted to their environment, even though he had not yet drawn an environment. Furthermore, the student incorrectly inferred that a new species had emerged. Help from the teacher was needed to get the student to think about other possible objects in his model, such as a background and a thrush. No further explanations or logical connections were made by this student. From this point of view, the student did not engage in higher levels of scientific reasoning. No improvement in modeling competence could be gleaned directly from the conversation with the teacher either.

The student drew a yellow and a brown snail, and he assigned behavior to the snails so they could move and split and change colors. A background (the surroundings) and the bird were missing from his drawing. In the preparatory scheme on the worksheet, they indicated that there should be two different kinds of backgrounds, so he understood all the aspects he was supposed to draw. This exercise was meant to get the student to first think about possible elements and behaviors in his model.

In general, after each simulation, this dyad as well as other dyads needed to change the behaviors or drawings in order to match their model with their own conclusions. Many students did not go beyond simply drawing some elements.

8.4.5.2 Dyad B: Class G3

This dyad practiced with SimSketch by drawing a rabbit and giving it all kinds of possible behaviors to see what happened. After some confusion about the exercises in the third lesson, they focused on modeling the evolution of the snail.

Student 1:	"You can see that green conceals better on green than green on orange." (21.42 min.) […]
Student 2:	"We have to make it complete." (26.35 min.) […]
Student 1:	"In fact a snail cannot really evolve." (29.29 min.) […]
Student 1:	"Now we are going to make a background." (30.34 min.) […]
Student 1:	"It must be a very simple model." (31.05 min.) […]
Student 1:	"The snail does not need to split right?" (33.00 min.)
Teacher:	"Splitting, or in this case reproduction, seems to be useful for natural selection. You need to make a background in which the bird sees the snail or not. The snail with the best camouflage colour stays alive and can reproduce himself." […]
Student 1:	"We need to make the background green, in order that the green snail can conceal better than the red snail." (36.10 min.) […]
Student 1:	"The bird eats the red snail and the green snail can split now." (41.25 min.)
Student 2:	"Actually the bird must split and eats snails. But the birds die eventually because there are no snails anymore."
Student 1:	"They now adapt to the background."

These students had some ideas about modeling, such as keeping it simple and making it as complete as possible. Student 1 in particular elaborated on his thoughts about the evolution of the snail. Student 1's statement that a snail cannot really evolve came out of the blue. Furthermore, they had some trouble with the behaviors they should use in SimSketch, such as splitting. The students thought about the environment they wanted to draw but again needed help from the teacher to really draw the background in SimSketch. Compared with the first dyad, this dyad engaged in higher levels of scientific reasoning, especially because they justified their ideas at the end of the lesson.

If we evaluate the exercises they completed on their worksheet, we can conclude that they gained a deeper understanding about how to model the evolution of the snail. This can be seen in Fig. 8.5. The students explained what kinds of changes they made in their model to arrive at a more realistic view. They understood that snails who adapted to the environment had a higher probability of surviving and reproducing, thus leading to more adapted snails.

Simulation round	Changes I made	Effects of the changes
2	Addition of a background	The snail is better camouflaged
3	Let the bird hunt	The bird eats the least camouflaged snail
4	The snail adapts	The bird does not see the snail anymore
5	Camouflaged snail reproduces	More camouflaged snails appear
6	The snail mutates	More adapted snails appear,and they are quite safe from the birds

Fig. 8.5 The notes on changes to the model made by dyad B in the student guide

Despite the fact that some of the changes were formulated in an incorrect way (e.g. in the simulations, individual snails do not mutate, but a snail's offspring can have a slightly mutated color), students showed progress by developing increasingly adequate models.

8.5 Conclusion

The aim of the present study was to gain insight into the role of drawing-based modeling in supporting scientific thinking and to obtain an impression of students' modeling competence by inspecting their reasoning with the models. We did this by investigating the effects of the lesson series on students' understanding of models and their scientific reasoning processes, which in turn reflected students' level of understanding. From the two cases that we presented, we could see that this was not trivial. Only in the second of these cases did we see a clear reference to the purpose of the model (it should be simple) and the relationship to reality: "a snail cannot evolve." In contrast to this, the student from the first group was very task-directed when working on the 11 modeling task and showed no meta-modeling knowledge. In such a way, by inspecting the students' statements, we obtained information not only about their reasoning about the domain but also on the extent to which they understood models.

8.5.1 Understanding of Models and the Role of Models in Science

The lesson series contributed to a slight increase in students' understanding of models. Effects were significant but small. Students specifically scored higher on the questions about the nature of models and multiple models. This seemed strange because, during the building process, students would be expected to better understand the need to test models because they had to test the different versions of the models while building them. A possible cause may be that they do not see that kind of testing as part of the modeling process but only as a technical procedure that needs to be followed to reach a certain goal. This idea was partly confirmed by the students' logs and statements, which tended to focus on technical matters. The reflection lesson involving a question and answer session with the researcher focused more on the aspects on which the learners improved.

There was a clear difference between the scores achieved by the general education G group and the preparatory higher education P group. The students in the P group scored higher on both the pre-test and post-test than the G students. Especially on the post-test, the P students scored higher, which was confirmed by the large effect size. This conclusion was expected because P students were expected to have a deeper understanding. Furthermore, the P students' drawings and discussions were of higher quality on average. In general, they drew more elements related to the evolution of the snail in their models, and they made more adaptations to their models. Despite these findings, it is important to point out that the G students also achieved a significant shift in scores from their pre-test to post-test even though the scores were lower than the P students' scores. Although the G group showed only a small effect, drawing-based modeling can still be a useful learning method for G students as well.

Overall, the progress in modeling competence was small but measurable. Although this may look disappointing at first glance, it should be kept in mind that this progress occurred after only four lessons. This means that this small increase is encouraging as a basis for further research involving more extensive modeling activities. What is important is that measurable progress was made, and it could be measured with a relatively simple measurement instrument.

8.5.2 Tracing Reasoning with Models

The use of drawing-based modeling in a lesson series can be used to support students' model-based reasoning. Moreover, in combination with assessments of modeling competence (Grünkorn et al., 2014), we can get an indication of students' modeling competence by having them work with the modeling tool, by tracing their model, and by observing the changes and predictions they make about the effects of these changes.

However, the modeling activities that students' recorded on their worksheets sometimes showed that the teacher intervened in the modeling process by scaffolding the learning process. A teacher's support has an influence on the modeling task and the scientific reasoning processes of the students. Although help is needed to reach higher levels of scientific reasoning, as can be seen in the videotapes of the dyads, if given in a spontaneous way, it may blur insights into how students develop their own reasoning. Part of the support the teacher had to give was related to the changes students had to make in their models in order to get them up and running.

Although the students practiced with SimSketch for at least 20 min in the first lesson, it took a while before they understood the principle of modeling in the third lesson. This principle implies that students first drew a model with some basic elements and behaviors. Scaffolding and probably more time to complete the task potentially led to learners expressing more ideas, explanations, justifications, and elaborations on their scientific reasoning processes.

Overall, SimSketch proved to be a modeling tool that can be used to foster and study modeling processes for students in lower secondary education. Drawing-based modeling provides a way for students to create computational models before they are able to program or process mathematical equations. Students were able to create reasonable models and reason about them even though a large amount of time still had to be devoted to technical issues with the tool, and scaffolding was required. To use the environment as a way to assess students' modeling competence, it is important to take into account the number and type of scaffolds given by the teacher. Despite this fact, students' models and reasoning logs in SimSketch will provide teachers and researchers with valuable insight into the development of students' modeling competence.

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