Exploring Middle School Science Students' Modeling Process and Strategies When Using a Computational Modeling Tool

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Abstract

In this study, we explore and characterize middle school science students’ modeling strategies when they are engaged in scientific modeling by the use of a computer-based modeling tool, Model-It. Three seventh grade science classes taught by three teachers at an independent school participated in the study. To capture students’ actions, statements during the dynamic modeling process and cognitive strategies they used, classroom videos and video recordings while students used Model-It were collected during 1999-2000 school year. The findings show that Model-It allows students to engage in modeling activities (i.e., planning, building, and testing) and exercise a variety of modeling strategies. This computer-based modeling tool provides a unique opportunity for students to experience various situations that require them to analyze a system, identify causal and correlational relationships, synthesize parts into a coherent model, test and revise the model. This research provides us with a richer understanding of middle school science students' computer modeling processes.

I. Introduction

Modeling is gaining popularity as an effort of science education reform (Clement, 2000; Gilbert and Boulter 1998; Gobert & Buckley, 2000; Harrison and Treagust 1996; see also, Giere 1991; NRC, 1996). Modeling is frequently used as an instructional tool in science education to highlight important information, such as concepts and structures of a system (Gobert and Discenna, 1997). Studies show that even young students (6 to 8 graders) can learn science concepts, scientific arguments, and the nature of science through the modeling process (Spitulnik, Krajcik & Soloway, 1999; Stratford, 1996; White, 1993; White & Schwarz, 1999).

Given that educational researchers wish to engage students in the practices of scientists, modeling allows students to experience the dynamic and ongoing nature of science (Brown and Duguid, 1989; Lehrer, and Romberg, 1996). In science, modeling, as one of the major scientific activities, helps scientists build, test, and evaluate models of phenomena for the construction of scientific knowledge (Black, 1962; Magnani, Nersessian, & Thagard, 1999). Modeling requires a series of cognitive strategies, such as analyzing, causal reasoning, and articulation, that are conscious and reoccurring mental activities and can be deliberately undertaken to accomplish cognitive goals (Hamilton and Ghatala, 1994).

Although modeling has been viewed as an important scientific reasoning process, little research investigates what cognitive strategies are involved when middle school science students build dynamic models, and how these strategies evolve over time when they become more familiar with the modeling process. The purpose of our study is to explore and characterize middle school science students' modeling strategies when they are engaged in scientific modeling by the use of a computer-based modeling tool, Model-It. The following research questions guide this study:

1. How do middle school science students use Model-It?
2. What are the modeling strategies do middle school science students use when building computer-based models?
3. What patterns of modeling strategies use do middle school science students demonstrate during the computer-based modeling process?
4. What scaffolds occur with students' modeling strategies?

This paper first reviews the literature on the use of modeling in school science classrooms. We then describe the design of the computational modeling tool, Model-It. The third part describes the settings and the research methods of the study. Next, we report our findings in the first year study. Finally, we indicate possible directions for future investigation.

II. Model and Modeling in School Science Teaching and Learning

Models and Modeling

A model is a simplified representation of a system, which concentrates attention on specific aspects or components of a system, such as ideas, objects, events or processes (Gilbert, Boulter, & Rutherford, 1998; Ingham & Gilbert, 1991). These specific aspects can be either complex, or on a different scale to that which is normally perceived (Gilbert, 1995). Models, therefore, could reveal the hidden structures or processes that are fundamental to an understanding of a system or a phenomenon (Glynn, Britton, Semrud-Clikeman, & Muth, 1989).

Additionally, the interdependent nature of the components of a system could be illustrated by representing a model. Creating such a model involves cognitive processes, such as identifying variables, making connections among variables, and verifying the accuracy of the model (Buckley, 2000, Harrison, 2000, Watson, 1968). We define this model formation process as “modeling.” In this study, we investigate modeling-related cognitive processes when students are using a computer-based modeling tool, Model-It.

Modeling Process and Strategies

A cognitive strategy is any conscious mental activity, such as rehearsal and elaboration, that can be deliberately undertaken to achieve a cognitive goal (Hamilton & Ghatala, 1994). Cognitive strategies include identifying problems, selecting approaches to their solution, monitoring progress in solving problems, and using feedback (Lefrancois, 1999). Cognitive strategies are the tools of intellectual activities. These strategies allow people to learn, to solve problems, to study and to understand. Students’ capability of using these strategies could predict their future accomplishment (White, 1998). Mastery of cognitive strategies allows learners to learn how to learn and to become lifelong learners (Lefrancois, 1999; Linn & Muilenbrug, 1996).

Modeling is one of the major scientific activities that could facilitate students to develop cognitive strategies. Stratford, Krajcik, and Soloway (1998) defined four modeling strategies:

- Analyzing: Decomposing a system under study into “parts.”
- Relational reasoning: Exploring how parts of a system are causally related.
- Synthesizing: Ensuring that the model represents the phenomenon in a complete way.
- Testing and debugging: Testing the model, trying different possibilities, and identifying problems with its behavior and looking for solutions.

They showed that high school students applied these cognitive strategies to build accurate and thorough models. Therefore, modeling can serve as an avenue for students to develop and apply a variety of cognitive strategies valued in science education, such as identifying questions, generating explanations, and using justifications (NRC, 1996; Penner, Lehrer, & Schauble, 1998; Stewart, Hafner, Johnson, & Finkel, 1992).

However, although the study has examined how high school students used a computer-based modeling tool, a number of questions still remain unanswered. Stratford et al. did not explore how the modeling strategies evolve over time when students become familiar with the modeling process and the tool, whether middle school students use these strategies, and how students at different grade levels demonstrate different patterns of building models. Additionally, as Gobert and Buckley (2000) indicated, there is no coherent theory that outlines the cognitive processes involved in modeling, so more in-depth work in this area still needs to occur.

III. Model-It

Rationale of the Design of Model-It

The modeling tool used in this study was Model-It, developed by the Center for Highly Interactive Computing in Education (http://hi-ce.org) at University of Michigan (Jackson, Krajcik and Soloway, 1999). Model-It was designed to support students, even those with only very basic mathematical skills, as they build dynamic models of scientific phenomena, and run simulations with their models to verify and analyze the results. This learning tool scaffolds students' modeling process with three modes—Plan, Build, and Test. In the Plan mode (Fig. 1), students create, define, and describe objects (e.g., stream, plants and people) and qualitative or quantitative variables associated with specific objects (e.g., the water temperature of the stream and the number of people). Next, in the Build mode (Fig. 2), they build causal relationship links between the variables that are presented by both verbal description and graphic representation. For data visualization, in the Test Mode (Fig. 3), Model-It provides meters and graphs to view variable values. As students test their models they can change the values of variables and immediately see the effects. If the simulation does not run as the way students expect, Model-It allows them to move back to the Plan or Build mode to revise objects, variables or relationships. The following screen shots demonstrate the major features of Model-It.

Model-It provides an easy-to-use object-oriented visual format with which students can define their models without having to use traditional programming. To use this computational modeling tool, students do not need to compute quantitatively, releasing computational burden. Students do not need to write equations to specify the relationship between two quantities and they can specify the relationship between two quantities either quantitatively or qualitatively without computation. This allows students to construct models quickly and easily so that they can focus their attention on the tasks of analyzing, causal reasoning, testing and re-examining their models.

Model-It provides various scaffolds to help students create dynamic models. For example, in the Plan mode (Fig. 1), students could easily choose images to represent objects in their environment by dragging an image from the bottom image palette. The verbal and graphic representations of a relationship on the relationship editor help students to articulate and specify relationships between variables in their model (Fig. 4). The meters and graphic lines in test mode (Fig. 3) are associated with specific variables. When students change the value of a variable through sliding a meter, they could see the changes of values of others variables that depend on this variable. This dynamic feature of this tool allows students to interpret and evaluate their model.

<u>Models Created by Model-It</u>

The model in Model-It is dynamic because it depicts natural phenomena as an interrelated system and allows students to manipulate certain variables in order to visualize the possible results (Richmond, 1991). The models created by Model-It portrayed a phenomenon as a dynamic system. Model-It can be used to create models for different subject matter, such as science, social studies, and history.

IV. Methods

The methods we employed are based on principles of design experiments as delineated by Brown (1992) and Collins (1999). Because this research took place in real classroom environments, we did not use random assignment of students or control groups. Instead, we gathered a variety of different types of data and sought to make holistic assessments of students' use of modeling strategies and how they used Model-It over time.

Settings

The study was conducted in three seventh grade science classrooms taught by three teachers at an independent school in a Mid-sized Midwest university city. In each of the three classrooms we identified two pairs of target students. Students built models two different times during the school year.

The first round of using Model-It occurred in a water quality curriculum unit, which included three sessions. In this unit, students were introduced concepts related to water quality (e.g., eutrophication, turbidity, conductivity, pH, and dissolved oxygen). They worked in pairs, collected data from a stream behind the school, analyzed data, and reported the results. Creating models on Model-It was designed to demonstrate their understandings of water quality. In the introduction session of Model-It, the teachers guided students to define what a model is and to discuss what objects and factors should be included in their water quality model. Students were asked to construct a model around a driving question that they wanted to answer. After a demonstration of the use of the tool, students worked in pairs to create models. In the second session, students continued creating or revising their models and the teachers gave instructions of how to make their models more complete and comprehensive and. Part of the third session was used to revise models and then students presented their models to the class.

This second round of using Model-It involved two class sessions in a decomposition unit. Similarly, prior to creating models students were introduced scientific concepts about decomposition. They conducted experiments, collected data, and reported their findings. Then students built their models around driving questions that they wanted to investigate. After building and revising their model, each pair of students presented their model to the whole class.

Data Collection

Two types of data were collected from the three science classrooms. First, video recordings while students used Model-It were collected from six target student pairs. These videos, also called process videos, captured activities on the computer screen and conversations of target groups (Krajcik, Simmons, & Lunetta, 1988). They allow us to characterize students' learning activities and interactions with Model-It during the modeling process. Second, classroom videos recorded the major class events relevant to the modeling process, such as the introduction session of the tool and students' final presentations of their models. These videos described the classroom context and captured students' presentations of their models.

Data Analysis

Data transcription

The primary data source is students' process videos. To analyze these videos, we transcribed them into a text format. Within each transcript, we first identified "episodes" during which students stayed on one specific mode of the tool (i.e., Plan, Build, and Test; see Figures 1, 2, and 3). Then under each episode, we identified "segments." In each segment, students kept the same interactional pattern with their partners, the tool, or the teacher. For example, in the plan mode, students created several objects and then the teacher came by and asked them about the description that they just filled in. The teacher's intervention was labeled as a beginning of a new segment and this new segment was ended when the teacher left. These transcripts captured: (1) students' use of the tool (e.g., creating a factor or a relationship, testing their model, or shifting to another mode); (2) students' activities when using the tool (e.g., making explanations, generating ideas, or seeking information); (3) thoughtful conversations between students; and (4) helps or supports provided by the tool, teachers, and peers. These transcripts were later analyzed by a coding scheme.

Developing the coding scheme

The coding scheme included three parts: modeling actions (i.e., students' use of the tool), modeling strategies (i.e., students' conscious activities during modeling) and scaffolds (i.e., supports or helps provided by teachers, peers or the tool. Scaffolding is a process in which a more knowledge individual provides support to another learner that helps the learner accomplish a task (Wood, Bruner, & Ross, 1976). Scaffolds allow students to complete a task they could not complete without the scaffold.

To document the action part of the scheme, we identified the main actions students performed in each mode (Table 1). For example, in the plan mode, students could use the tool to create, modify, and delete objects. The actions in each mode constitute the action part of the coding scheme.

The strategy part of this analysis scheme was generated through an iterative process. We first use Stratford et al. (1998)'s taxonomy of cognitive strategies for a trial coding. The coding results guided us to reframe and add strategies we observed from the process videos. We then created a refined scheme for another trial coding and repeated the refining process until the scheme accurately portrayed students' modeling strategies. We classified modeling strategies into six categories: planning, searching, synthesizing, analyzing, explaining, and evaluating. Under each category, we specified and defined several modeling strategies that students would demonstrate in the modeling process (Table 2).

We also identified types of scaffolds that could be provided by the tool, teachers, and peers during the modeling process (Table 3). For example, Model-It breaks down the modeling process into plan, build, and test modes. These three modes potentially sequence the modeling process (code 3.1.1 in Table 3). Additionally, suggestions from teachers and peers might accelerate the modeling process and increase the accuracy of the model. This scaffold part allows us to investigate the possible interactions between students' use of strategy and types of scaffolds.

Data coding and reduction

Three researchers analyzed and coded process videos. The transcripts were imported into a qualitative data analysis tool, Nud*ist®, and coded based on the analysis scheme. This tool allows us to search by one code or multiple codes and to make reports that indicate the instances when strategies or scaffolds were used. By using searching and reporting commands, we reduced the data corpus and obtained the text data that allow us to answer: What strategies were the most frequently used in each mode by different student pairs? What strategies were occurring with scaffolds? How did the frequency of using strategies change during different sessions? Table 4 is one example of data tables that shows the frequency of students' use of strategies in the Plan mode across three sessions in the water quality unit.

To visualize how students used the tool and obtain an overview of students' activities in each session, we created a "process map." In process maps, different modes (i.e., plan, build, and test modes) are shown by different color stripes (Appendix 1). The length of the color stripes was decided by the amount of time students spent on a mode. By using these color stripes, process maps illustrate the patterns and sequences of shifting among the three modes in each session. They also allow us to compare how each student pairs' use of the tool was changed over time.

Data synthesis

To answer our research questions, we synthesized the information from the process maps, the frequency counting, and transcripts. We identified the patterns and sequences of how students used strategies and how they switched among the modes within and across three sessions. We compared differences of the patterns among target students' pairs and identified possible interactions among patterns of switching modes, the use of strategies, and the use of scaffolds. Based on these patterns and comparisons, we generated assertions. Assertions were validated by confirming evidence from the data corpus (Erickson, 1986).

Classroom videos were coded and analyzed in detail; rather, they were used to display the major class activities of modeling, triangulate assertions generated from the analysis of process videos, and indicate possible explanations of students' performances.

Findings

Overview of students' use of Model-It: Patterns of activities (Research question 1)

Water quality unit:

The process maps show that during the first session in water quality unit, students spent most of their time on planning. After the first session, students sometimes went back to the plan mode to create or modify objects and factors, but usually did not stay longer than three minutes in each episode. Two pairs stayed more than five minutes at the plan mode during their second session for reasons. DA and PA encountered a technical problem and had to recreate their objects and factors. AT and RN spent relatively more time on planning their model during the second session because RN was absent in the first session and they were involved more discussions and negotiations about their model in the second session. In the third session, four target pairs did not plan at all. While other pairs mainly switched back and forth between the build and test modes in the last session, KN and WR moved to the plan mode relatively often (6 episodes). The transcripts indicated that while other pairs did minor revisions by modifying the relationships in the build mode during the last session, KN and WR did several major revisions of their model structure by deleting and changing objects and factors.

All three pairs began building relationships in their first session. Compared with their first session, students spent relatively longer time on building in their second session. Although the time they spent on the build mode was approximately the same, the patterns of shifting were different. While AT and RN had 12 episodes of building, other pairs had less than four episodes in the same session. That is, AT and RN shifted frequently among the plan, build and test modes, whereas others had fewer shifts and longer episodes in the build or test mode. The number of strategies showed that instead of clicking around, AT and RN purposely shifted among the three modes. Compared with other pairs, AT and RN demonstrated relatively more instances of using strategies in the build mode.

Additionally, as the models were more complete, the preceding episode of building changed from planning to testing. In the first session, fifteen of 21 preceding episodes of building were planning, while in the last session, seven of 21 preceding episodes of building were planning. The purposes of building in the modeling process seemed to change over time. During the first session, building included more creations of relationships and was an extension of planning, but during the last session, building involved more deletions and modifications of relationships to make the model more accurate and comprehensive based on the testing results.

During the first session, four out of six pairs started testing and the total time each pair spent on the test mode was less than five minutes, except AT who worked alone. Across the three sessions, each testing episode was seldom longer than five minutes. After testing the models, students either switched to the build or plan mode to solve the problems they found. The minor revisions, such as modifying a change of degree of a relationship, could be made in the build mode, while the major revisions, such as a change of the model structure, need to be done in the plan mode. As the models were more complete, in the third session, four pairs only shifted between the build and test modes, while KN and WR who made more major revisions switched back to the plan more often.

<u>Decomposition unit:</u>

In the decomposition unit, students spent most of their time on planning in the first session, and built and tested their models in the second session. This pattern is very similar to their first round of using Model-It. One discrepancy between the two units shown by process maps is that students' modeling process in the decomposition unit involved fewer shifts among modes and less cycles of plan-build-test. When students created models of water quality, the total number of episodes in the first and second sessions ranged from 20 to 40, whereas in the decomposition unit, the total number of episodes ranged from 10 to 20. Students had fewer shifts among modes in their second round of using Model-It and the cycle of plan-build-test could be easily identified on the process maps. Three pairs' modeling processes involved one cycle of plan-build-test, while the other repeated this cycle twice. It seems that as students were more familiar with the modeling process and the use of the tool, they might realize what they could accomplish in each mode and made fewer shifts (and trials) to figure out what they were supposed to do in each step of modeling. As mentioned previously, switching back to the plan mode after testing might be an indication of major revisions of their models. In the decomposition unit, once students tested their models, most of them never moved back to the plan mode. This indicates that students might be able to envision how their model worked during the planning stage, so they did not have to go back to make changes of the model structure as they did in the first round of modeling.

Patterns of Students' Use of Strategies (Research Questions 2 and 3)

Plan mode

Students created objects and factors in the plan mode. Usually they first generated ideas about what objects and factors should be included in the model. They then identified objects and created factors that were associated with it. For example, they created "factory" as an object and "the amount of emission" as their factor. Most students filled in the descriptions of objects and factors. Students assigned a factor either as qualitative or as quantitative. They sometimes renamed the scales of a factor and reset the initial value of a factor.

According to process maps, most of the students' planning activities were done in the first session and they went back to the Plan mode sometimes during the later sessions. In each session, the nature of planning was slightly different. During the first session, the purpose of planning was to create objects and factors based on their initial plan for their model. During the second and third sessions, creating objects or factors became a means to make their model more complete and precise, especially after students have already tested their models.

The most frequently used strategies in the plan mode were identifying objects and factors (29 out of 101 instances across three session in water quality unit**),** discussing objects and factors

(23/101 instances) and deciding the course of actions (15/101 instances) (see Table 4). The following segment is an example that illustrates the typical activities and modeling strategies students had in plan mode during the first session.

Conversation and action	Strategy and scaffold
DA: Should we do D O (Dissolved Oxygen)?	[Identify factors]
Pete agrees.	
They click on the screen and a new object window comes up.	
PA: no, we need a factor with stream.	
DA: but we need an object to create a factor, don't we?	[Discuss factors]
PA: no, that's gonna be the stream.	[Peer conceptual scaffold]
DA and PA create a new factor, DO%, associated with the stream object.	
PA: now, let's build it.	[Decide course of action]

Among the three sessions of water quality 1, students used more strategies during the first session (Table 4). During the second and third sessions, students demonstrate fewer strategies in the plan mode, because usually prior to the plan mode (i.e., test or build mode), they already decided which objects or factors they wanted to create in the Plan mode. Creating factors and objects were to increase the complexity of models or make better connections among factors and objects. Testing models and creating relationships in the Build mode help students realize the needs of creating or modifying objects and factors. Students created objects or factors not only for planning purpose but also for making a more complete and complex model.

The change of the nature of planning also can be seen from students' descriptions of objects and factors. In their first session, the descriptions of objects and factors were more descriptive, such that "the stream supports life," "house: people live here," or "tree: give oxygen to the air." In the later sessions, the discussions and descriptions in the plan mode involved more cause and effect statements that showed their considerations of how a certain object or factor connects to other factors in the model. The conversation below illustrates change in the explanatory nature of planning during the second session.

Conversation and action	Strategy and scaffold
RN opens the image folder.	
AT reads the file names: people, bug, fish. Okay, let's have bug.	[Identify objects]
AT and RN create a new factor, Bug.	
RN: more bugs mean what?	
AT talks to another student near him: are more bugs good or bad for the stream?	[Discuss objects]
[The student's response is inaudible.]	[Peer content scaffold]
AT: okay, let's not do bug. Well, people.	[Identify objects]
AT and RN select image again.	
RN: or trash or something.	[Identify objects]
RN: What's that person?	
RN refers to the custom icon on the palette.	
AT: people, people, people.	
They create a new object, people.	

RN: Will more people dump trash?	
AT: Well, it could be more people polluting or doing bad stuff.	[Discuss objects]

In the second and third sessions, students created factors and objects to increase the complexity of models or make better connections among factors and objects. Testing models and creating relationships in the Build mode help students realize the needs of creating or modifying objects and factors. Students created objects or factors are not only for planning purpose but also for making a more complete and complex model. Therefore, in the later sessions, planning, building, and testing became connected activities and led to one another.

Build mode

The main activities in the build mode were creating and modifying relationships. Students made direct cause and effect connections between variables. The relationship editor opened after students connected two variables. Students used the verbal descriptions or graphic displays provided in Model-It to decide how to depict their relationships (see Fig. 5). The following segment taken from the second session of the water quality unit presents students' typical activities in the Build mode (Tape 018-KN&WR).

Conversation and action	Strategy and scaffold
KN and WR are in the build mode.	
KN: OK, then conductivity would affect water quality.	[Specify a relationship]
They make a relationship between conductivity and water quality.	

They agree that stream- conductivity would "decreases" water quality. Then WR suggests "a little" (for the degree of change).	[Tool scaffold] [Discuss a relationship]
KN and WR finally agree KN's suggestion of "more and more", because "high conductivity indicates poor water quality."	

The episode that occurred prior to students' activities in the build mode influenced what students did in the build mode. If the prior activity of building was planning, going to building was usually to create relationships. If the prior activity of building was testing, going to building was to create, modify or delete relationships. That is, testing seems to promote students to recognize the need of creating more relationships or modifying certain relationships. Again, in the later sessions, planning, building, and testing became related activities and the activities in one mode led to certain changes in another mode.

When the main activities in the build mode were creating and modifying relationships, the most frequently used strategies in the build mode were discussing relationships (28/132 instances), deciding course of action (19/132 instances), explaining why and how (15/132 instances), and specifying relationships (14/132 instances) (Table 5). Although discussing factors and objects, generating ideas, and identifying factors and objects were usually used in the plan mode, students demonstrated these strategies occasionally in the build mode. It seems that making connections and creating relationships promoted students to discuss factors and objects for their models. Building could be viewed as an extension of students' planning activity. Additionally, students also carried out solutions they proposed in the test mode (6/132 instances).

Particularly, in the last session, most prior activities of building were testing. The segment below shows that building mode allowed students to revise their models based on the testing results.

Conversation and action	Strategy and scaffold
In the Test mode, AT and RN open all meters, play simulations, and change the value of one variable.	[Tool scaffold: manipulate representations]
AT: oh, that's not right. Wait, that's right.	
AT: well it should affect more than that.	[Identify an anomaly]
AT: That's weird.	
AT: I guess that trash doesn't affect that much. Let's do this.	[Interpret the result and propose a possible solution]
They go back to the Build mode and modify the relationship between trash and quality, change the degree to a lot.	[Carry out solution]

Test mode

Students used testing to simulate how the change of one variable affects one or several other variables. Students opened up meters, changed the meter values of the independent variables, and observed the changes of values of dependent variables on the simulation graph on the bottom of the testing window (Fig. 3). Changing the independent variables allowed students to observe changes in the dependent variable and determine if their models worked as expected. Usually, students found some unexpected model behaviors and went back to either plan or build mode to create, modify objects, variables and/or relationships. Therefore, test mode usually became the last mode that students worked on during each session, because if they were satisfied with the testing results of their model they would stop working on it (see "process maps", appendix 1).

In the test mode, students used several modeling strategies. Students frequently critiqued and interpreted test results (34/135), identified anomalies (20/135), and proposed a solution for their unexpected findings (14/135) (Table 6). The following segment shows that through testing (e.g., manipulating meters and playing the simulation), KN and WR realized a need of creating a factor between conductivity and dissolve oxygen factors.

Conversation and action	Strategy and scaffold
KN and WR open all the five factor meters and click on "play."	[Manipulate representation]
KN: Why dissolved oxygen always changes?	[Identifying an anomaly]
WR: Stream conductivity really goes up (refers to the peak on the graphic simulation window), wait….	
T asks them to stop and says "now talk to each other if this is really working?"	[Teacher task scaffold]
Students scroll the simulation window and find the peak of conductivity.	
WR: this is where you put the dissolved oxygen up.	[Identify a solution]
KN: OK, so dissolved oxygen goes up conductivity goes…	
WR: goes up.	[Peer scaffold]
WR: we need a factor to put them in between them.	[Propose a solution]

KN: we need to link them.

Although students can only create relationships in the Build mode, testing encouraged students to think further about their relationships and students occasionally made connections (6/135 instances) and discussed relationships (4/135 instances) (Table 6) in the test mode. Also, they discussed objects and factors they missed or inappropriate connections they made (7/135) and made decision about what to do next (12/135).

Scaffolds and the Use of Strategies

Plan mode

Students' use of modeling strategies in the plan mode frequently occurred with the tool, teacher or peer scaffolds. Among 101 instances of using strategies in plan mode across the three sessions, 70 of them occurred with scaffolds. Scaffolds were provided relatively evenly by the tool (26), teachers (25) and peers (19). Filling in the description boxes seemed to encourage students to identify and discuss factors and objects (18/70 instances). Most of teachers' scaffolds were conceptual (16/25). Teachers' conceptual scaffolds involved discussions with students in terms of model structure, problem solving on model function, helping understand factors, objects and relationship and testing. In the following segment, the teacher conceptually guided students to reconsider what a factor means and how to describe their factor.

AT and CD create a new factor, the speed of photosynthesis, for the object of trees and plants. The teacher comes by.

Teacher: Photosynthesis? That's good.

Students type in "give off oxygen" in the description box.

Teacher: That's something that it does. So what's the factor?

CD: We put dissolved oxygen.

Teacher: well, let's think about that. Think about what's your definition of factor is.

AT: Is it something that affects the situation?

Teacher: You have the object, okay. How does it now affect what surround it? It does this [give off oxygen], okay.

CD: It provides more oxygen.

Teacher: Right now what's your object here? Trees and plants?

Teacher: You have photosynthesis. You want to make sure that your description reflects that factor, whatever is your thinking. okay?

Students rephrase their description of photosynthesis.

Peer scaffolds also played an important role (19/70 instances). Students frequently looked for content and conceptual scaffolds from their peers. They worked collaboratively to generate ideas, make decisions, and become each other's resources.

<u>Build mode</u>

Among 132 instances of using strategies in the build mode, 110 of them occurred with scaffolds (Table 8). Different types of scaffolds occurred in the build mode than in the plan mode. About 50% of the scaffolds occurring in the build mode were provided by teachers, while tool scaffolds (31/110) and peer scaffolds (28/110) occurred less often. The "because statement" window seemed to be most successful tool scaffold in the build mode that probed students to discuss relationships between variables. Making explanations, seeking information and discussing factors and objects were highly associated with teacher scaffolds. Most of the peer scaffolds were conceptual (21/28).

Test mode

Among the tool scaffolds provided in the test mode, manipulating representation (37/119 instances) seemed to support students in identifying anomalies, interpreting testing results and identifying solutions (Table 9). Students thus could make connections between the objects andvariables they had created. Teachers also provided scaffolds to support students' strategy use in the test mode (54/156). There was no clear pattern, however, about what types of teacher scaffolds helped students the most. Compared with the frequency of the tool (48) and teacher scaffolds (59), the number of peer scaffolds was relatively lower (12).

Conclusion

Model-It created a learning environment for middle school science students to exercise a variety of modeling strategies. Students identified objects and factors of a system, discussed relationships between factors, interpreted testing results, and carried out proposed solutions. The built-in scaffolds probe and support students to plan, analyze, and synthesize, and provide instant feedback to evaluate their models. Computer-based modeling allowed students to use modeling strategies.

While many of modeling strategies were used in the modeling process, some strategies, such as stating goals, elaborating ideas and justifying arguments, were rarely used by the students. This may suggest that more tool scaffolds are needed in order to promote students to demonstrate these cognitive strategies.

Future investigations

Model (artifact) analysis

Artifact analysis will inform us about the quality of students' models and indicate possible interactions among students' use of strategies, students' use of the tool, and their models.

Longitudinal study to look at students' change over time

As we described previously, in the decomposition unit, students demonstrated different activity patterns comparing to those in the water quality unit. This indicates that students modeling strategies might also change with increase expertise of modeling. We plan to collect data across school years and curriculum units to look at how students' use of the tool and strategies change over time.

Comparison of modeling process and strategies between experts and novices

We predict that students modeling process will be more similar to experts' modeling process with the increasing exposure of computer-based modeling. This can be verified by a comparative study of experts and novices.

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