Comparison of modeling practices of experts and novice learners using a dynamic, learner-centered modeling tool

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Abstract

This study compares the computer-based modeling practices of novices and experts when they used Model-It, which is a dynamic computer-based modeling software program. The novice learners were six pairs of seventh students. Student pairs' conversations and computer activities during three modeling sessions were video recorded when they created their water quality models. Five advanced Ph. D. students were considered experts of water quality and modeling. The experts participated in two working sessions individually. Their thinking processes were captured by a "think aloud" technique and their computer activities were also video recorded. The video recordings were transcribed and coded based on a well-refined coding scheme. The purpose of the study was to characterize modeling practices demonstrated by experts and novice learners and compare their use of scaffolds that were provided by the modeling software.

This study confirmed previous expert-novice research findings, which is that experts have superior knowledge structure than novices from both our "process data" and final models. Experts could articulate their goals clearer and more frequently monitor their foci. Experts seemed to make frequent connections to their experiences, while novices did not do so although they had the relevant experiences. The study also demonstrated that novice learners as young as seventh graders could demonstrate expert-like modeling practices and create models similar to experts with appropriate scaffolds. The study suggests that both subject knowledge and modeling knowledge are necessary for students to benefit from modeling practices.

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Introduction

A model describes scientific phenomena; it allows scientists to formulate and test hypotheses. Modeling, an "authentic" activity that is promoted by National Research Council (NRC) and American Association for the Advancement of Science (AAAS, 1993; Barab & Duffy, 2000; NRC, 1996; Gobert & Buckley, 2000; Roth & McGinn, 1998; Stratford, Krajcik, & Soloway, 1998), is central to a scientist's daily practices. Engaging students in the practices that share features with those of scientists' provides a context for students to construct knowledge, integrate content, inquiry and epistemological understanding (Clement, 2000; Gobert & Buckley, 2000; Spitulnik, Krajcik, & Soloway, 1999;Penner, 2001). With the increasing use of computers in science and science education, computer-based modeling has become a powerful way to facilitate students' modeling activities (Penner, 2001; Jackson, Stratford, Krajcik, & Soloway, 1996; Windschitl, 2000).

Since obtaining expertise takes quite a long time (Ericsson, Krampe, & Tesch-Roemer, 1993), the earlier the better for a student to start learning knowledge and skills of certain practices such as modeling. Over the past ten years, numerous researchers have used computer-based modeling tools to support learners as they engage in modeling tasks (Jackson, Stratford, Krajcik, & Soloway, 1996; Mandinach, 1989; Resnick, 1996; Schwarz, 1998; White & Frederiksen, 1998). However, little research has attempted to characterize students' computer-based modeling practices and there has been little (if any) research done about middle school students' computer-based modeling practices. Middle school students face a number of difficulties in creating and using models for science learning, such as limited experience with creating and using models, lack of

advanced mathematical skills (Jackson, et al., 1994). Understandings about middle school students' modeling practices would provide insights into how a computer-based modeling tool supports students' science learning, what features in tools are useful to science learning, and how a modeling tool should be integrated into science curricula.

Some cognitive science researchers consider meaningful learning to be a continued, organizational development of conceptual understanding that moves learners from a novice state toward an expert state (Royer, Cisero, & Carlo, 1993). Therefore, an expert and novice comparison might reveal some insights into how to help novices develop expertise in a specific science domain. In addition, a comparison could allow educators to realize how experts perform their expertise in a domain. By using the same modeling program for the comparison, we hope to inform the software design so that the tool includes appropriate scaffolding that emulates the major features of professional practices, but is still accessible to students as novice learners. Scaffolds are intentionally designed supports that help students to create models that they otherwise could not (Metcalf, Krajcik, & Soloway, 2000; Wood, Bruner, & Ross, 1976).

The following research questions guided this research:

Q1. What do the modeling practices look like for novice learners and experts?

Q2. How do novice learners' modeling practices change over time?

Q3. How do experts and novice learners use the scaffolds in a dynamic computer-based modeling tool?

In this study, we explored how experts and novice learners use the same dynamic, learner-centered, computer-based modeling tool--Model-It (Jackson, et al., 1994; Metcalf et al., 2000). We use the term "modeling practice" to characterize modeling activities and

reasoning that are involved in modeling processes. The experts in this study are five advanced Ph. D. students with both domain specific knowledge (water quality) as well as modeling expertise. The novice learners are 7th graders from three science classes. When it is not necessary to make a distinction between experts and novice learners, they are both called "users." The purposes of the study were to observe what experts and novice learners' modeling practices look like, and also understand how the scaffolds in the modeling software were used.

Literature review

Modeling practices

Earlier research done by Stratford et al. (1998) characterized high school students' modeling process with the use of Model-It. They found that students engaged in four types of activities during modeling: (1) <u>analyzing</u> (decomposing a system under study into parts); (2) <u>relational reasoning</u> (exploring how parts of a system are causally related); (3) <u>synthesizing</u> (ensuring that the model represents the complete phenomenon); and (4) <u>testing and debugging</u> (testing the model, trying different possibilities, and identifying problems with its behavior and looking for solutions). As science educators envision ideal science learning including engaging students in inquiry activities that approximate to the real-world science, the above activities during modeling in essence are scientific practices in the real world. They can serve as an avenue for students to develop and apply a variety of scientific practices valued in science education, such as identifying questions, generating explanations, and using justifications (NRC, 1996; Penner, Lehrer, & Schauble, 1998; Stewart, Hafner, Johnson, & Finkel, 1992).In this study, these scientific practices related to the modeling process are regarded as modeling practices.

Scaffolding

Scaffolding is defined as a set of purposefully designed assistance that helps learners to conduct difficult tasks, such as modeling, that would otherwise be out of their reach (Wood et al., 1976). Scaffolds can come from various sources such as computerbased modeling program, teachers and peers in the learning environment who are using the software (Fretz et. al, 2001). Although experts might not need scaffolds in order to create a model, we hypothesized that experts can provide insights about how to build scaffolds in computer-based modeling tools that were designed for novices. Our effort is to make the connection between real science and science learning through computerbased modeling in schools.

Experts and novices comparison

Research that examined the development of expertise found two different aspects of expertise that distinguish experts and novices in general as well as modeling. The first difference is the domain specific knowledge. Experts differ from novices not only in the amount of knowledge they possess, but also in the organization and accessibility of knowledge--their knowledge structures. Experts tend to "chunk" information according to the hierarchical structure of concepts in a certain domain (Anderson, 1993; Bransford, Brown, Cocking, Donovan, & Pellegrino, 2000; Romance & Vitale, 1999). This difference may be related to poorly formed, qualitatively different, or nonexistent categories in the novice representation (Chi, Feltovich and Glaser 1981). However, the structure of knowledge in a certain domain usually is not explicit to novice learners. The second difference is the understanding of the nature of models and modeling. We will refer to this understanding as modeling knowledge hereafter. Grosslight and his

colleagues (1991) interviewed 33 mixed-ability 7th graders and 22 11th graders from an honor class. They compared the students' understanding of the nature of models and modeling to four experts in the field and found that novices and experts differ in terms of the understanding of the purposes of models and modeling; the relationship between a model and the phenomenon that is modeled, and when and how to change a model. One of the implications is that students need "meta-conceptual" lessons about models in order to reflect and understand the nature of models and the process of models and the process of models.

Expertise is also relative. An expert in one field or one specific aspect of a field might not be an expert in other fields or other aspects of a field. Expertise can also vary among experts. In a research by Kozma and Russell, they define novices as undergraduate chemistry students comparing to professional chemists as experts (Kozma & Russell, 1997). In another study, advanced PhD students in Physics were considered as experts and undergraduates as novices (Chi, Feltovich, & Glaser, 1981). The definition of experts seems to be related to the purpose and the nature of the research. Research about "expertise" also suggests that as the difficulty of a task increases, observed expert performance decreases (Bereiter & Scardamalia., 1993). Therefore, in our research, with a tool that is used for middle school students and with water quality knowledge required in a general sense, we classify our PhD participants as experts.

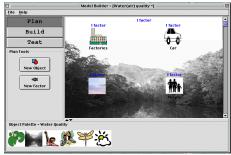
Methods

The research described in this paper was part of a larger project that investigates middle school students' computer-based modeling practices and software design. In order to help readers understand the research design, the first section of this part introduces the computer-based modeling software called Model-It. The following sections will describe

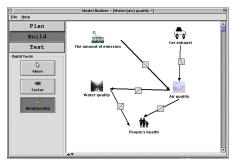
participants, time line, settings and how data were collected for both novice and experts, respectively. The last section describes how the data were analyzed.

Model-It program

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 the University of Michigan (Jackson, Krajcik and Soloway, 1999; Metcalf et al., 2000). 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.









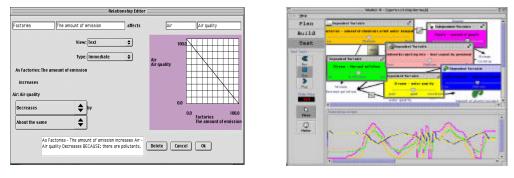


Figure 3

Figure 4

There are three modes (Plan, build and test mode) in Model-It. Model-It provides various scaffolds to help students create dynamic models. The first scaffold users used in

Model-It was the "process map" with the plan, build and test buttons. This process map is supposed to decompose complex modeling tasks into three modes to release users' cognitive workload. In <u>plan</u> mode (Fig. 1), the world view, object editor and factor editor are the major scaffolds. Users can easily choose images to represent objects in their environment by dragging an image from the bottom image palette. Object and factor editor as well as factor editor are the major scaffolds at <u>build</u> mode. 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. 3). The map view, meter and graph window are the major scaffolds at <u>test</u> mode. The meters and graphic lines (Fig. 4) are associated with specific variables. When users 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 users to evaluate and revise their models easily.

Participants and time line

Novices

Novice learners were from three seventh grade science classrooms taught by three experienced teachers at an independent school in a mid-sized Midwest university city. In each of the classroom, the teacher identified two pairs of target students. The students were representative of the classes. Another major consideration for choosing student pairs was that student participants should be talkative in order that we can make our inference from students' conversation. A brief introduction of the target students is listed in Appendix 1. Students were involved in two rounds of computer-based modeling in this

study. Students' initial modeling happened in a water quality unit in March, 2000. Students then were involved in another round of modeling practice in a decomposition unit in late March and early April, 2000.

Experts

Experts were five Ph.D. students from School of Natural Resources and School of Public Health during the summer of 2000 at our University. The major requirement for participants was "graduate student who knows <u>water quality</u> very well." Participants were each briefly interviewed by phone to assess their experience better. They all had rich content knowledge about water quality and modeling experience. More information about them can be found in Appendix 1.

Settings and data collection

<u>Novices</u>

Computer-based modeling during the water quality curriculum unit included three class periods. In this curriculum unit, teachers first gave lessons to introduce concepts that were related to water quality, such as eutrophication, turbidity, conductivity, pH, and dissolved oxygen. Students then worked in pairs, collected data from a stream behind the school, analyzed data, and reported the results (Novak & Gleason, 2001). Creating models with Model-It happened after students had analyzed and reported their data. Modeling was designed to demonstrate their understanding of water quality as well as making connection among concepts that they have learned. During the introduction session of Model-It, the teachers demonstrated how to use Model-It to create a model. The whole session of introduction of Model-It lasted about 20 minutes in each of the three classes. Students, then, were asked to work in pairs and construct their model

around a driving question (Krajcik et al., 1998) that they wanted to answer. Students did similar investigation for a decomposition unit after the water quality unit. After finishing data analysis, they worked on Model-It to create their decomposition models.

Experts

The experts received the same amount of time of tutorial session and the same way of instruction as the teachers did to their students on how to use Model-It. Because the researcher had been in the three classes observing how the teachers introduced Model-It to students, he was able to use the same way to introduce Model-It to the experts. On the first day, the researcher spent about 20 minutes to demonstrate how to create an "air quality" model and also showed the participant how to "think aloud" because the experts were supposed to work alone. Each expert then was asked to use about 45 minutes, which is of the same length as on class period, to create a model about "water quality". The researcher told the participant that he might remind him/her to think aloud in order that the researcher understood what they were doing but would not say anything else unless asked. On the next day, the researcher spent about 50 minutes to show the process video tape to the experienced learner and asked him/her to articulate some of the modeling episodes about their thinking. The basic idea was still to clarify why she/he did certain things. Questions clustered around four groups: first group of questions was about modeling process (patterns and sequence). Here are some sample questions: How did you build the model? Could you explain your model to me? What else would you want to accomplish if you have more time? The second group of questions was about "How did he/she make use of the scaffolds in Model-It?" Here are some of the sample questions: what features in Model-It helps you to build your model?

Was there any limitation that restrained you to build an accurate model? Do you have any comment about how to modify the program? The third group of questions was about their strategies about how they built their models. Here are some of the questions: When you were asked to build a "water quality" model, what came in mind? Was it the whole model or part of it? How complex was it? In the hindsight, what strategy do you think you used to build your model? The fourth group of questions was about their research experience and modeling expertise. Here are some of the questions: Your model looks very specific, is this related to your real research work? What modeling experience do you have? What tools did you use?

There were two reasons for why the experts had to come back. The first reason was that the researcher might not understand the whole model or did not have enough time to make sense of the model. The researcher kept silent during the modeling processes. Another reason was that the researcher only showed the participant some of the episodes but not the whole process according to the time order in the process videos. If a participant still could remember why they did what, it might mean that he/she had made meaningful decisions instead of just thinking something accidentally. This process was used by Chi and her colleagues (Chi et al., 1981, p. 123). They used two trials to test if the experts' and novices' categorization was meaningful. Like the first day, the debrief sessions were videotaped and field notes were collected during the interviews. In addition, each expert provided samples of their work in order to help the researcher to know their background better.

Student pair' conversation vs. expert' "think aloud"

We could only capture what novices or experts were thinking during their modeling process by their verbal data. Since students were supposed to be talkative and had to talk to each other to create their models, we assumed that both novice learners and experts had similar chances to express their thinking. It was difficult to create a similar environment for the experts as the students in class, expert's individual thinking was captured by a "think aloud" technique (Larkin, 1984). From literature, we have seen that think aloud does not affect participants' thinking process too much (Ericsson & Simon, 1984).

Data sources

Both novices' and experts' modeling activities on computer screens as well as conversations happened at the same time were recorded by videotapes called "process videos" (Krajcik, Simmons, & Lunetta, 1988). These process videos were good enough for a different researcher who was not at the first place to figure out what happened during the modeling session in detail. There was one case that one of the experts could not save her model because of a technical problem, the research created her model later by watching the process video tape. The debrief sessions with individual experts were also recorded by videotapes. Altogether, there were eighteen process video tapes from the water quality unit for novice learners for water quality unit. Another twelve process video tapes from a following decomposition unit was used to look at students' modeling practices over time. There were five process video tapes and five video tapes of debriefing sessions for the experts. Each tape lasted about 45 minutes. Both experts' and student pairs' final water quality models were collected. Altogether, there are five

experts' models, six novices' models for water quality unit and six models for decomposition unit.

Data analysis

Characterization of modeling practices and frequency counting

The primary data source for comparison is the process videos of both novice learners and experts. The debrief videos for the experts were used only for double checking of our assertions when necessary. The first step for working on the process videos was transcribing them into a text format. The transcripts included detailed description and some verbatim transcriptions of modeling activities. These transcripts were then coded based on a well-refined coding scheme. The coding scheme was based on the one by Stratford (1996). Appendix 2 shows the coding scheme for modeling practices. Since this study works primarily with modeling practices, the coding scheme does not include other codes such as administration codes (e.g. 1.1.1 school...), modeling action codes (e.g. 2.1.1 Creating object) as well as scaffolds codes (e.g. 3.1 Tool scaffolds). The frequency of occurrence of each modeling practice was counted with the help of a qualitative research analyzing tool—NUDIST (Richards, 1999).

Mode movement charts

In the transcript, each time when the users change mode (i.e. plan, build, or test), there is a time mark. To visualize the mode movement and length of stay at each mode, we created a "mode-movement chart" for each pair of the novice learners and each expert according to the time marks. On the charts, plan, build, or test mode is demonstrated by different color stripes (appendix 5). Since the novice learners spent more than one class sessions to complete their model, a two-minute block in blank separates different

sessions. Both novices and experts' frequency of mode moves were counted and shown in appendix 6.

Model layout analysis

For all the models, only model layouts were analyzed to see if there is difference on model structure between novices and experts that ties to their modeling practices. For each mode, circles are used to identify the central variable in the model. In the water quality models, the central variable is water quality. Dashed lines were used to illustrate the biggest patterns where variables are grouped using identifiable criteria. Squares were used to denote what were the identified criteria for grouping (Appendix 7).

Findings

Q1. What do the modeling practices look like for novice learners and experts?

Modeling practices	Novices	Experts
	(314 instances)	(220 instances)
Deciding the course of action	40, 13%	6, 3%
Discussing objects/factors	71, 23%	44 , 20%
Explaining why and how	37 , 12%	47 , 22%
Critiquing/interpreting test results	32 , 10%	12, 5%
Discussing relationships	31 , 10%	29, 13%
Seeking information	16, 5%	7, 3%
Identifying/proposing solutions	15, 5%	3, 1%
Making connection to experiences	5, 2%	21 , 10%
Stating goals	3, 1%	11, 5%

Table 1 Most frequently used modeling practices are listed in the following table.

Model-It allows 7th graders to exercise some expert-like modeling practices

Table 1 shows the most frequently modeling practices for both novices and experts. Detailed tables for all the modeling practices and their frequencies are in appendix 3. From the table we can see that novices could demonstrate some similar modeling practices, such as discussing objects/factors, discussing relationships, critiquing/interpreting test results, identifying/proposing solutions to anomalies. These modeling practices seemed to be confirmed by the experts as necessary for constructing a model.

However, novices differed from experts in both the frequency of some modeling practices as well as the quality of those practices. For example, novices demonstrated much more instances of "deciding the course of action." While it was natural to talk to each other about what to do next because the students were working in pairs, but often neither of the two students could tell what they should do next. A typical conversation went like this:

(After creating a relationship)

We suggests to move the icons, Katy complies.

Katy is asking and thinking what to do next

Wyne: Plants can affect conductivity.

Katy: yeah.

(They then create a relationship between plants and conductivity) Experts expressed clearer goals as well as scenarios for this models

Also from table 1, we can see that experts stated their goals for what they want to model at the very beginning and gave their scenario in their explanation (**11**, 5%). Usually their actions were consistent with what they intended to do. For example, during his modeling process, expert Matt said that he was creating a model for water quality in the river system in Ann Arbor and the Midwest area. His explanation was validated by the data and experience he had with this scenario later on. Experts seemed to be exporting their mental models using Model-It during the modeling processes that fulfilled their goals. Stating goals might not be unique to experts since they were asked to tell what they

were doing, however, being able to articulate their goals and monitoring their focus seemed to be the difference between experts and novices.

It was also very rare to hear students' to "stating goals" as part of their "planning (3, 1%)." The following is a typical conversation between two students when they talked about what they were supposed to model. It was surprising because teachers had asked students to plan on what they need to model.

----PLAN MODE

000120 Students choose the "water quality" unit from the pop up window.

Katy: What should we do?

Wyne: Ok, put the sun on the top (he drags the "sun" image from the image palette.

Wyne puts the name as "sun" and ask K about the description.

Katy says she can not type, Wyne says he will.

They talk about "big sunlight" or "orange ball", but they do not think they are good. Students do not make it as their object.

Then they drag another image from the picture palette-"house".

They name it as "house".

Wyne puts in "brown, wood" in the description window.

Katy: oh, like "the amount of...what it produces?"

Wyne changes the name to "our house". Katy agrees.

Wyne then changes the description as "family waste".

Students were supposed to talk to each other when creating the model, but their conversations were most initiated as response to the program, such as naming an

object/factor, giving descriptions to the objects/factors they created. Since there was no space for students to fill in their driving questions and scenarios in the program, novice learners' driving questions and scenarios were not explicit. The program lacked a component that could possibly promote students to state their goals so that to be more focused on what they were modeling on.

Experts' explanations were more supported by evidence

Detailed analysis of the transcripts of process videos also reveals the difference of the nature of both experts' and novices' explanation. Experts are required to provide explanations about what they were thinking and doing. Therefore, it is not surprising that they had to make explanation (47, 22%) more than the novice student pairs did (37, 12%). However, the difference between experienced and novice learners is that experts provide more evidence to support their explanation. Usually they would refer to their field experiences, literature or phenomena more automatically and often. Overall, the five PhD students provided 21 instances (10%) that they refer to their own experience or literature'' when they made explanation. The arguments usually were supported by evidence. For example, the following excerpt illustrates the richness of understanding and the way an expert made his explanation.

03213 (Mike) Create relationship: As pervious surface increases, water quality decreases by more and more.

Mike: (reads and types) because water delivered to the river gets accelerated... Mike: (starts to explain) so what happens is that there are a lot pollutants that human put on their lawns, on their sewer, on their parking lots like oils,

insecticides...all kinds of things, this usage actually is correlated with population on the pervious surfaces.

Mike: What pervious surfaces does is put a nice mixing of rain...

mix of the pollutants and rush right into the rivers without going through any soil or letting biotic organisms to work to degrade the poisons and chemicals...when you send rain water into the river... the river will go higher...a lot the rivers go to sewage channels,...during the storms, the sewage treatment center can not process pollutants...so they just dump the sewage directly into the river, they can dilute some of the pollutants but overall it has very negative effect.

On the other hand, even novice learners had completed the investigations and written up their reports, they did not refer to those experiences very much. Novice learners' explanation was rarely supported by evidence or referrals to their real life experience (5, 1%) or even their investigation that happened right before they worked on Model-It. Explanation was not often either (37, 12%). There was not much disagreement or argument that was made by novice learners. Usually, one student worked on the program and typed, this student could also be the person who contributed the most, or another student made the suggestions and the student who was typing just put whatever the other student said. A typical conversation might like this:

001059 Arno: we add a new factor, okay? Salt on the bridge.

Rose: that's good.

Create a new factor: BRIDGE, salt on bridge, text, initial value medium, fill in description.

Arno: another factor, oil?

[Ss created these two factors based on a researcher's suggestions about water toxicity. Still, Rose kept quiet.]

Rose: umh.

Create a new factor: BRIDGE, oil, text, initial value medium, fill in description. Arno: what else do you wanna add?

Rose: umh...

Arno: sun, bugs.

Rose doesn't give an answer.

We have two possible explanations for this. One is that Rose did not have a holistic understanding of the whole model so that she could not give support to Arno's suggestions. Another reason is that students were not in the habit of making connections and make explanation with evidence.

Experts were more deliberate than novice learners in general during the modeling processes

By looking at the mode-movement charts (Appendix 5) that visualize the trajectories of mode movement and modeling activities in an chronicle order for both novices and experts, we can see that patterns of movement between different modes vary between experienced and novices learners. In general, the experts had fewer moves between modes and longer duration at a mode than the novice learners during their initial computer-based modeling processes (Appendix 5 and 6).

Detailed analysis of the transcripts of process videos shows that experts engaged in more focused and structured tasks at each mode. For example, expert Luis spent 14 minutes in plan mode, then 30 seconds at build mode only for modifying a factor, then he

spent another one minutes in plan mode to finish his objects and factors creation. He never came back to plan mode again. He spent another 20 minutes in build mode and then about nine minutes in test mode only to know how to use the test feature. According to the debrief analysis, he said he did not need test because he had spent the last five minutes in build mode to visually check his relationships. He was sure that the model would work as he predicted. Some experts also had many movements between modes, but their stay at some modes was very short and more in terms of utilities of the program. For example, Dave only stayed at plan mode one time, but he has more moves between build and test because he tried to find an anomaly in the program. The only exception was an expert, Charles. He had more moves between plan and build mode was because he was not used to the way of creating a factor. He kept assigning factors to wrong objects so that he had to go to build mode to find the wrong factors he made to delete or modify them. As experts had fewer movement between modes and had fewer backward operation along the order of plan \rightarrow build \rightarrow test mode, it might indicate that they had better understanding about models and modeling beside much more concrete domain specific content knowledge. On the other hand, novice learners had to move between modes in order to check what objects or variables they have missed or not accurate, they have to go back to plan or build mode more often after testing to fix problems they found mostly in terms of content. The following excerpt is from a novice learners' process video transcript that shows how students discovered anomalies in their model:

In the test mode, Arno and Rose open all meters,

Play simulations, and change the value of an independent variable. Arno: oh, that's not right. Wait, that's right.

Rose: well it should affect more than that.

Arno: That's weird.

Rose: I guess that trash doesn't affect that much.

Let's do this

They go back to the Build mode and modify the relationship between trash and quality, change the degree to a lot.

During the modeling processes, experts organized their variables in a pattern as they have had all the relationships between variables. Experts seemed to have a more complete pattern of their models when they were creating models could also be confirmed by the structure of their models (appendix 7-1 and 7-2). Almost without exception, the experts' models have much clearer structures than novice model builders. For example, one expert put all the variables that affect water quality on the top of the screen, the water quality variable in the middle, then all the variables that water quality affects on the lower part of the screen. The patterns were clearer for the other experts' models as illustrated by the researcher using circles and dashed straight lines. Novice learners could also have similar model structure as the experts had, but this was not common across the six pairs.

Q2. How do novice learners modeling practices change over time?

Our research is part of a larger project, in the successive unit of water quality unit, there was a decomposition unit. By looking at the mode movement charts (appendix 5) we found that during this second round of using Model-It novice learners had much less moves and longer duration at each mode. This could be seen a sign that novice learners have gained more expertise in computer-based modeling.

Besides the biggest pattern of mode movement, we could find that the frequency and quality of students' modeling practices also changed (table 2). For example, students had fewer instances of identifying/proposing solutions ($15\leftrightarrow 5$). Since students could discover some of the errors before they went to test their model, students found less anomalies that needed their solutions. Although "deciding the course of actions" still happened a lot because students were working in pair to make a decision, students seemed to be clearer about what they are supposed to do. The following is an example that demonstrates the way a student talked to her pair about what to do next:

Rose: Now we should probably test it.

Rose: Let me give this another factor though.

One surprising change is that the frequency of "explaining why and how" decreased significantly $(37\leftrightarrow7)$. One explanation for this is that when students became more familiar with the scaffolds built in the software, they became less engaged in filling those articulation boxes. This seemed to be a negative effect of using scaffolds in the software.

Table 2. A comparison of frequency change of some modeling practices between novice learners' initial modeling in water quality unit and a later decomposition unit.

Modeling practices	Water Quality	Decomposition
Deciding the course of action	40	35
Discussing objects/factors	71	73
Explaining why and how	37	7
Critiquing/interpreting test results	32	11
Discussing relationships	31	27
Seeking information	16	15
Identifying/proposing solutions	15	5
Making connection to experiences	5	3
Stating goals	3	3

Q3. How do experts and novice learners use the scaffolds in a dynamic computer-based

modeling tool?

Mode→	Plan mode	Build mode	Test mode
Major	World view; Image	Map view; factor	Map view; meters and
tool	palette; object/factor	editor; relationship	graphs
scaffolds	editors	editor	
Novices'	Discussing and	Discussing and	Critiquing/interpreting
modeling	identifying objects/factors	identifying	test results;
practices		relationship;	identifying anomalies
			Deciding the course
			of actions;
Experts'	Discussing and	Discussing and	Critiquing/interpreting
modeling	identifying	identifying	test results;
practices	objects/factors; explaining	relationship;	Deciding the course
	why and how	explaining why and	of actions;
		how	

Table 3: Tool scaffolded modeling practices in the three modes of Model-It

Given the complexity of what happened in novices' classes, some times it was difficult to tell the sources of scaffolds that students received. For example, sources of scaffolds can be the software Model-It, teachers as well as researchers or students peers. Even when there was a conversation between students initiated by the software, students might turn to their teachers or peers for further scaffolding. On the other hand, some experts might not need scaffolds although they were new to Model-It because they are familiar with other modeling tools. Therefore, from the tool scaffold standpoint, we only provide descriptive accounts of the modeling practices that were supported by the software scaffolds according to students' or experts' actions and conversation. We did not provide frequency count, however. Table 3 briefly summarizes the tool scaffolds that were mentioned at the software introduction part. Since even novice students did not have any difficulty moving between plan, build and test mode in Model-It, it seemed that this "process map" has been successfully used. The following part will describe in detail how the software scaffolds at each mode facilitated students' and experts' modeling practices. Plan mode

Since the object and relationship editors require users to specify an object or a factor, the scaffolds facilitated discussion and specification of objects and factors for both novices and experts. The images were handy and situated the context of a water quality model. The following are some differences between novices and experts in terms of the use of scaffolds.

Novices

Novice learners filled in the windows with low accuracy or did not fill in the space because they did not knowing what to write. They were not explicit about the reasons in most of the cases about why they set up a certain initial value to a factor or what they put in the description boxes. It seemed that novices needed more scaffolds to understand the concepts and rationale of computer-based modeling. For example, one pair of students created a water quality model that did not have water quality variable in their model until the teacher pointed it out.

Novice learners used the image palette the same way as the experts. They started from making sense of the images, then use the images to create their objects. This may attribute to the way that the program was set up. It seemed that having more images for users, especially novices are necessary. Novice students expressed that there were not enough images for them.

Experts

Most of the experts used the scaffolds as required and felt comfortable and made sense of them in plan mode. Only Cathy gave long names to factors because she did not realize that she was supposed to put descriptions of factors in the explanation boxes, until she went to build mode and saw the long names of her factors. Experts filled in almost all the spaces that they were requested to give description or explanation. They were more precise and depth about their initial values and description statement when they talked aloud and filled in the description windows. They used more quantitative values for factors and more precisely because they gave reasonable rationales or referred to literature to support their explanation.

Almost all of the experts used <u>only</u> the images from the image palette or by looking at the ready-made images in the program. They moved their images often to check what they had or what they missed. They admitted that the visualization helped them to think. Almost all the objects they used were dragged from the image palette. This means users want the convenience. Also, several experts mentioned that they did not have the images that they wanted. Expert Charles commented that the images were suggestive.

One interesting and possibly important finding is that almost no exception, all the five experts confused objects and factors. Maybe they did not use the same way to create their model as the way designed in Model-It. The following is what happened with Dave as one of the experts to show how they confused with objects and factors:

00:06:18 (Dave) Select another image (house) and create an object "land use" Description: "the amount of farm in this area"

Dave: We can do different land use too. I will start with ag. culture

The "amount of farms" should actually be a factor here. Another example was with expert Leo, he was very familiar with another computer-based modeling tool called STELLA:

0:10:00 (Leo) Create #7 object: residences

Leo: I am going to putting "new residences" as a new factor there, oh, new object.

The reason for the confusion might be that experts did not think in terms of an object first, then its factors. During a debrief session, Cathy said that she thought about factors in her research. Objects were implicit because a factor must deal with an object so that it even did not need to be mentioned.

Build mode

Both novices and experts started from reading the verbal description in order to specify their relationship. Some of them checked all the possible relationships they could chose before they created a relationship. Even experts admitted that the scaffolds in relationship editor helped them with the creation of their model. For example, Cathy said that she was a visual person, the relationship editor made it easier for her to create and see the relationship she created. Both novices and experts use the map view to check what factors they have had and what relationships they have had.

The relationship editor with articulate window that explains certain relationship seemed especially important for helping students to discuss and specify their relationships. The following is an excerpt from our process video transcript:

001433 Carla thinks the relationship between pH and water quality could be both increase and decrease.

Carla: we can do two of them.

Alan agrees, so they create two separate relationships for pH value and stream quality.

This was at the very beginning when they first used Model-It. Because they have considered the complexity of the relationship between pH value and stream quality, they quickly picked up the bell-curved relationship after they discovered that the program has built in at a later instance. On the other hand, experts demonstrated much better explanations for the reason why they specified a relationship than novices did when they talked aloud or filled in the articulation windows. Also, experts were more rigorous about the graphic representation of relationship on the relationship editor. For example, during a debrief session, Cathy said she realized the graph but she did not use graph to justify her relationship. She said the graph was not precise for her. For example, the 1:1 scale was not always true.

Test mode

The dynamic meters and colorful line graphs helped both experts and novices when they were testing their models. The visual feedback on the meters and graphic representations seemed to be especially helpful to the novices because the scaffolds helped them to critique and interpret their models' behaviors, discover anomalies and require them to provide a solution to what they found as unexpected.

Overall, experts seemed to look at the scaffolds as a way to flesh out their ideas. For the novice learners, the scaffolds were something that really made modeling

accessible to them. Some time we felt even students could create a model that "works", which means students filled in all the required fields and could test a model, they did not actually understand what they were supposed to build and whether their model was good or not good.

Possible conclusions and discussion

This study confirmed expert-novice comparison literature that experts differ from novices in the way they organize concepts in a certain domain (Anderson, 1993; Bransford, Brown, Cocking, Donovan, & Pellegrino, 2000) . Both mode movement charts and detailed analysis of transcripts of process videos support the conclusion. The following are other possible conclusions that we might draw from the results. <u>Middle school students could obtain some expert-like modeling practices in a relatively</u> <u>short time using appropriate computer-based modeling tool</u>

From the comparison of the most frequent used modeling practices we can see that students could demonstrate major modeling practices such as discussing/specifying objects/factors, discussing/specifying relationships, critiquing/interpreting testing results. However, the quality of those practices differs from those of experts. For example, experts had clearer goals and were more focused on tasks. Experts' explanations were more supported by evidence and tie to their own experiences. The results of another expert and novice study (Linn & Clancy, 1992) showed that explicit explanations from experts could help students learn complex problem-solving skills, such as programming. Meanwhile, it also demonstrated that students are more ready to make sense of experts' explanation and commentary to a problem solving process such as programming when

they have experienced the problem solving process. This finding suggests that students' learning from modeling might be an iterative process.

There is much evidence in literature, which suggests that students rarely provide genuine evidence to support their explanation (Kelly, et al., 1998; Kuhn, 1989, 1993). Therefore, our finding about the lack of evidence in students' explanation was not unique. Given that modeling practices should be an iterative process for novices, we are expecting more and more explanations with the support of evidence. However, students cannot do it automatically.

More scaffolds are needed to support students' modeling knowledge

Although novice learners could demonstrate "expert-like" modeling practices and create high quality models, they need more help from the tool, teachers or peers. Concerning scaffolds from the tool, first, built-in articulation boxes for putting in driving questions and scenarios seem to be necessary. Because Model-It was rebuilt one Java platform without all the original scaffolds (Stratford, 1996), we unintentionally did research that compared a modeling tool with and without driving question boxes. Second, more images that tie to students experiences are necessary. It will motivate students greatly if they can upload their own images. Third, a scaffold that demonstrates the hierarchical structure of a model might help students to design a model in the way that similar to that of experts.

Concerning scaffolds from teachers, more teacher coaching might help students to benefit more from their modeling practices. The quality of novice learners' models could have been improved if the students filled in all the required space and really make sense of what they are supposed to fill in. This could have been done with the help from their

teachers. However, we have to acknowledge that computer-based modeling is also new to the teachers, too. In the study reported here, it was also the first time that the teachers used Model-It.

Both subject knowledge and modeling knowledge is necessary for students to benefit from modeling practices

The reasons for experts to have better models seemed to be that they did not have as many new things to learn as the novice learners because they had already been familiar with both general concept of model and modeling and water quality content knowledge. Students have learned basic concepts and did water quality investigation before they created their water quality model, however, they were unable to make connection between what they have learned. Students need different ways to make connection between what they have learned (Gutwill, Frederiksen, & White, 1999). It seems that modeling tools like Model-It can help students make connections between concepts as well as concepts and reality.

For the literature we found that experts differ from novices also in terms of their modeling knowledge (Grosslight et al., 1991). For example, what is an object? how to name it? how to describe it? what is a variable? how to name a variable, how to describe it and how to set up the initial value; what is a relationship and how to decide the relationships? This type of knowledge should be taught prior to students' modeling practices.

Future directions

We have found that in the real class setting it was very difficult to have a post hoc debrief sessions for the novices even right after their class. The expert-novice comparison

has provided some directions about what to observe and ask when students are creating their model. A researcher or researchers as participatory observer(s) might help with both coaching and probing students' thinking processes.

It is not clear yet about what elements really affect students' modeling practices. Our second year data also include students' test sheets that reflect their content understanding; students' pre-and post-interview data that demonstrate students' understanding of modeling knowledge. The difficulty for doing an comprehensive analysis is that for process videos, students worked in pair or small groups, while tests and interviews were from individual students. Unless we have a way to reduce the data, it will be very hard to make connection between students' modeling practices, their content knowledge, and their modeling knowledge.

We have also had all the final models from our new data sets, too. Another remaining question is how does modeling practices, as well as modeling processes that relate to modeling products (the quality of final models). This will be done by two graduate students' dissertations (but not only for this question!).

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