

Expert Models and Modeling Processes Associated with a Computer-Modeling Tool

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ABSTRACT: Holding the premise that the development of expertise is a continuous process, this study concerns expert models and modeling processes associated with a modeling tool called Model-It. Five advanced Ph.D. students in environmental engineering and public health used Model-It to create and test models of water quality. Using “think aloud” technique and video recording, we captured their computer screen modeling activities and thinking processes. We also interviewed them the day following their modeling sessions to further probe the rationale of their modeling practices. We analyzed both the audio–video transcripts and the experts’ models. We found the experts’ modeling processes followed the linear sequence built in the modeling program with few instances of moving back and forth. They specified their goals up front and spent a long time thinking through an entire model before acting. They specified relationships with accurate and convincing evidence. Factors (i.e., variables) in expert models were clustered, and represented by specialized technical terms. Based on the above findings, we made suggestions for improving model-based science teaching and learning using Model-It. © 2006 Wiley Periodicals, Inc. *Sci Ed* 90:579–604, 2006

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INTRODUCTION

Models are commonly used in science. They allow scientists to formulate and test hypotheses. "A model is a representation of an object, event, process or system" (Gilbert & Boulter, 1998). Models can be personal such as mental models, communicative such as expressed models, or public such as consensus models. The process of developing models, modeling, is central to a scientist's daily practices. Engaging students in the practices that share features with those of scientists', such as modeling, provides a context for students to construct knowledge and integrate content, inquiry, and epistemological understanding (Clement, 2000; Gobert & Buckley, 2000; Penner, 2001; Spitulnik, Krajcik, & Soloway, 1999). Promoting modeling in science learning and teaching is consistent with the calls from the National Research Council ([NRC], 1996) and American Association for the Advancement of Science ([AAAS], 1993) for using "authentic" science inquiry in science learning. For example, the National Science Education Standard content standards encourage science teaching to "develop descriptions, explanations, predictions, and models using evidence" (NRC, 1996, p. 145). Modeling can serve as an avenue for students to develop and apply a variety of scientific practices valued in science, such as identifying questions, generating explanations, and using justifications (NRC, 1996; Penner, Lehrer, & Schauble, 1998; Stewart, Hafner, Johnson, & Finkel, 1992).

Recently, there has been a call for model-based teaching and learning (MBTL) (Buckley et al., 2004; Gobert, 2000; Linn, 2003). MBTL is an approach to changing student conceptions and to improving student scientific understanding (Duit & Treagust, 2003). "Model-based teaching is any implementation that brings together information resources, learning activities, and instructional strategies intended to facilitate mental model-building both in individuals and among groups of learners" (Gobert, 2000, p. 892). Comprehensive theories and best practices of MBTL have been reported in an edited book (Gilbert & Boulter, 2000), and in a special issue on MBTL in *International Journal of Science Education* (vol. 9, issue 9, 2000).

As a type of MBTL, computer-based models and modeling have received particular attention in science education (Stratford, Krajcik, & Soloway, 1998; Windschitl, 2000). Over the past 10 years, many researchers have developed computer-based modeling tools to support elementary and secondary school students in scientific modeling (e.g., Mandinach, 1989; Resnick, 1996; Schwarz, 1998; White & Frederiksen, 1998). The following partial list of computer-based modeling programs has been introduced for K-12 science teaching: STELLA (e.g., Costanza, 1987; Mandinach, 1989; Steed, 1981); LOGO (Papert, 1980) and later StarLogo (e.g., Colella, Klopfer, & Resnick, 2001; Resnick, 1994); Model-It (e.g., Fretz et al., 2002; Jackson, Stratford, Krajcik, & Soloway, 1996; Metcalf, Krajcik, & Soloway, 2000); ThinkerTools (e.g., White, 1984, 1993); KidSim/Cocoa (Smith, Cypher, & Spohrer, 1994); and BioLogicaTM (Buckley et al., 2004). These programs made computer-based modeling possible for K-12 science teaching. Computer modeling facilitates students in effective transformation among models of different types: mental models, expressed models, and consensus models. As the computer model and the reflected mental model interact, the modeler's understanding of the nature and scope of both are liable to change (Carmichael, 2000). Computerized models can be used for scaffolding scientific understanding (de Jong et al., 1999; Ebenezer, 2001; Korfiatis, Papatheodorou, Stamou, & Paraskevopoulos, 1999; Linn & Muilenburg, 1996; Monaghan & Clement, 1999; Stewart et al., 1992; Windschitl, 2001).

This study focused on one popular computer-modeling tool, which is a dynamic, learner-centered, computer-based modeling tool called Model-It (Jackson et al., 1996; Metcalf et al., 2000). Much research has been conducted using Model-It. Jackson and her colleagues

designed Model-It using the learner-centered design approach with built-in scaffolding, and they made computer-based modeling accessible to middle school students (Jackson, Stratford, Krajcik, & Soloway, 1996). Stratford and his colleagues (1998) found that Model-It can engage high school students in a range of cognitive strategies in computer-based modeling, such as analyzing, relational reasoning, synthesizing, and testing and debugging. Spitulnik, Stratford, Krajcik, and Soloway (1998) used Model-It to engage students in discussing and building relationships and explanations of a subject area. Wu (2002) used Model-It as part of student inscriptional practices, and characterized middle school student inscriptional practices as construction, interpreting, reasoning, presenting, and critiquing. Other studies identified students' modeling practices to be related to planning, searching, analyzing, synthesizing, explaining, and evaluating (Fretz et al., 2002; Zhang, Wu, Fretz, Krajcik, & Soloway, 2001).

The above studies involving Model-It all focused on student performances. We know little about how experts may use scaffolded tools such as Model-it differently than students. Cognitive science research has shown that meaningful learning is a continuous development from a novice state toward an expert state (Royer, Cisero, & Carlo, 1993). Obtaining expertise takes a long time (Ericsson, Krampe, & Tesch-Roemer, 1993), and the earlier the better for a student to start obtaining knowledge and skills of certain practices such as modeling. Alexander (2003b) proposed a model of domain learning (MDL) in school settings. The MDL suggests that progression from novice to expert may go through three stages: acclimation, competence, and proficiency. Lajoie (2003) claims transition from novice to expert is a nonlinear process; there can be many different trajectories or paths for novice learners to progress toward expertise. The transition from novice to expert can be accelerated when a trajectory for change is plotted and made visible to learners. In order to understand and facilitate the developmental trajectory of learners using Model-It, an important first step is to understand how experts may perform using Model-It, which is the purpose of this study.

Expert–novice research over the past four decades identified the following reliable differences between novices and experts: (a) experts possess extensive and highly integrated bodies of domain knowledge, (b) experts are effective in recognizing the underlying structure of domain problems, (c) experts select and apply appropriate problem-solving procedures for the problem at hand, (d) experts can retrieve relevant domain knowledge and strategies with minimal cognitive effort, and (e) experts have better meta-cognitive ability to monitor their own progress when completing a task (Alexander, 2003a; Anderson, 1993; Bransford, Brown, Cocking, Donovan, & Pellegrino, 2000; Chi, Feltovich, & Glaser, 1981; Chi, Glaser, & Farr, 1988). More recent novice–expert research also demonstrates that (a) the acquisition of knowledge and skills is accompanied by socioemotional changes (such as in interest, values, and identity), (b) the process of gaining expertise is assisted by other people and artifacts, (c) expertise occurs in socioculturally significant contexts, i.e. learning relates to solving socially significant problems and performing tasks (Hatano & Oura, 2003).

Expertise is specific to a domain (Alexander, 2003b; Hatano & Oura, 2003). An expert in one field or one specific aspect of a field may not be an expert in other fields or other aspects of a field. The criteria for defining experts can also vary. For example, in one study by Kozma and Russell, they defined novices as undergraduate chemistry students who were compared to professional chemists as experts (Kozma & Russell, 1997). In another study, advanced Ph.D. students in physics were considered experts and undergraduates novices (Chi et al., 1981). Research on “expertise” also suggests that as the difficulty of a task increases, observed expert performance decreases (Bereiter & Scardamalia, 1993).

More specifically related to the novice–expert difference on models and modeling, Grosslight and his colleagues (1991) studied the differences in understanding about models among 12–13 year olds, 16–17 year olds, and university teachers. They identified three

qualitatively different levels. At level 1 (the most preliminary level), models were thought of as either toys or copies of reality, which could be incomplete because the producer of them wished it to be so. At level 2, models were thought of as consciously produced for a specific purpose, with some aspects of reality being omitted, suppressed, or enhanced. At level 3, a model was considered as being constructed to explain or develop ideas, rather than being a copy of the reality. Therefore, from novice to expert, there appears to be a transition from perceiving models as copying reality, to models as approximating reality, to models as representing or explaining ideas.

In this study, we focused on both the characteristics of experts' models and their modeling practices using Model-It. This study uses the term "modeling practice" to characterize the modeling as well as reasoning activities that are involved in modeling processes. Previous research done by Stratford et al. (1998) characterized high school students' modeling processes with Model-It. They found that students engaged in four types of activities during modeling: (a) analyzing (decomposing a system under study into parts), (b) relational reasoning (exploring how parts of a system are causally linked or correlated), (c) synthesizing (ensuring that the model represents the complete phenomenon), and (d) testing and debugging (testing the model, trying different possibilities, and identifying problems with its behavior and looking for solutions). Identifying characteristics of experts' models and modeling practices can help novice learners understand the target performance objectives on modeling, thus informing science teaching by providing intentionally designed scaffolding which helps students perform modeling tasks that they otherwise could not accomplish (Metcalfe et al., 2000; Wood, Bruner, & Ross, 1976). Within the context of modeling water quality using Model-It, this study will answer the following research questions:

1. What are the expert modeling practices on water quality?
2. What are the characteristics of expert models on water quality?

METHODS

Model-It

The modeling tool used in this study, Model-It, was developed by the Center for Highly Interactive Computing in Education (<http://hi-ce.org>) at the University of Michigan (Jackson et al., 1996; Metcalfe et al., 2000). Model-It was designed to support students with only basic mathematical skills, as they build dynamic models of scientific phenomena, and run simulations with their models to verify and analyze the results. As seen in Figures 1–4, Model-It has three modes (plan, build, and test mode) that sequence the modeling process. In the plan mode (Figure 1), a user (or users) creates, defines, and describes objects (e.g., stream, plants and people) and specifies qualitative or quantitative variables (in the version of Model-It this study used, variables were factors) associated with specific objects (e.g., the water temperature of the stream and the number of people). Next, in the build mode (Figures 2 and 3), the user builds causal or relational links between the variables that are presented by both verbal description and graphic representations. An example of a typical relationship in verbal representation is as follows: As the amount of farmland increases, stream–water quality decreases because rain can wash pollutants such as fertilizer, pesticide into the stream. For data visualization, in the test mode (Figure 4), Model-It provides meters and graphs to the user to view and change variable values. One meter and a colored graph line correspond to one variable. As students test their models, they can change the values of independent variables and immediately see the effects on dependent variables from both meters and graphs. If the simulation does not run the way the user expected, Model-It

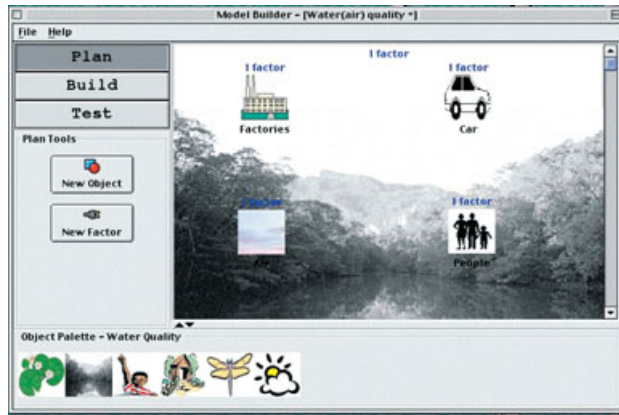


Figure 1. The typical graphical interface for the plan mode of Model-It. (Color version is available on Wiley-InterScience)

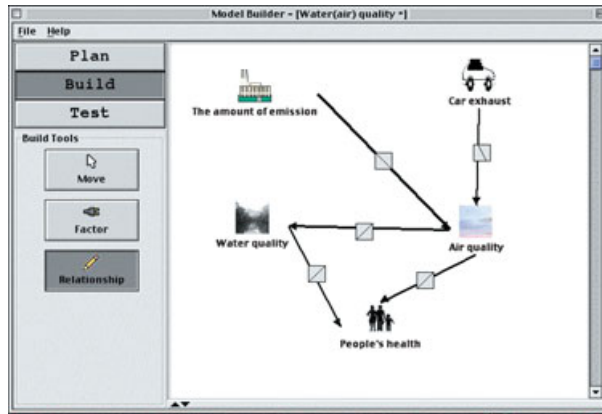


Figure 2. The typical graphical interface for the build model of Model-It. (Color version is available on Wiley-InterScience)

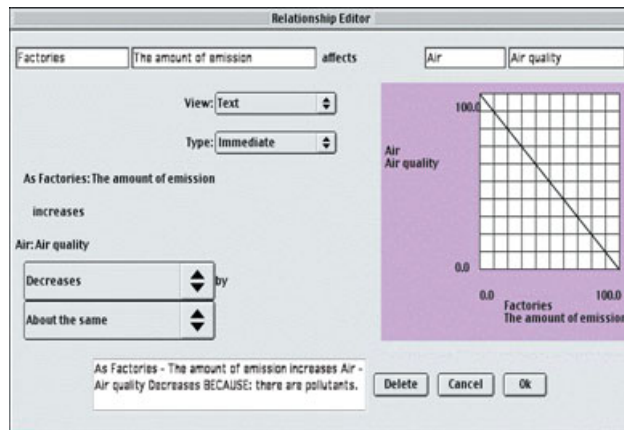


Figure 3. The typical graphical interface for the build model for verbal relationship specification in Model-It. (Color version is available on Wiley-InterScience)

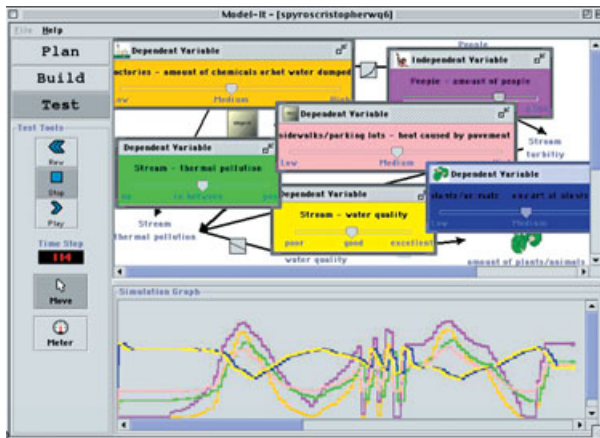


Figure 4. The typical graphical interface for the Test mode of Model-It. (Color version is available on WileyInterScience)

allows the user to move back to the plan or build mode to revise objects, variables, or relationships.

Participants

Because the term “expert” is a relative term, and the modeling tool, Model-It, was developed mainly for middle school students who have rudimentary water ecological knowledge, we considered Ph.D. students in water resources engineering and public health as our experts in terms of their domain knowledge. This does not necessarily mean that they are proficient in using Model-It, as it is new to them as well. Consistent with the research questions stated above, our interest was to find out if those knowledgeable Ph.D. students on water resources engineering and public health would demonstrate expert modeling performance in using Model-It and how it would be exhibited.

The five participants were Ph.D. students from the School of Natural Resources and the School of Public Health who researched water quality during the summer of 2000 at a large mid-western research university. The main criterion for identifying participants was their content knowledge on water quality, which was initially assumed by their doctoral study specialization. The five participants were each briefly interviewed on their background, and found that they all had extensive content knowledge about water quality and modeling experience, although no one had used Model-It before. Table 1 presents detailed information on their personal characteristics and their domain expertise.

Data Collection Procedure

On the first day, the researcher (the first author) spent about 20 min demonstrating how to create an “air quality” model and showed the participants how to “think aloud” because they would be asked to work alone. The demonstration focused on major features of Model-It in the order of plan, build, and test mode. However, he also emphasized that a modeler should go back to revise his/her model in plan or build mode if they found needs for revision after testing. Each participant was then given the exact same task: “take about 45 min to create a model about water quality.” The researcher told the participants 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. The whole modeling processes were videotaped

TABLE 1
Characteristics of Expert Participants

Characteristics	Expert				
	Leo	Cathy	Dave	Mike	Charles
Gender	Male	Female	Male	Male	Male
School	SNRE	SNRE	SNRE	SNRE	SPH
Year in Ph.D. program	5th year	5th year	3rd year	4th year	3rd year
Domain specialty	Resource, policy and behavior; master degree in computer science. Works in GIS lab	Water resources; just finished her dissertation	Wetland restoration and mitigation consulting in a firm; river systems; water level fluctuation and water source in wetlands in southeastern Michigan	Streamside riparian wetlands and their role in river ecosystems; generally familiar with aspects of river ecosystems and their influence on water quality, taught basic water chemistry to graduate and undergraduate students	Environment health science; master in public health and water quality management
Modeling experience	Taught how to use STELLA for living	Diagram models from her dissertation obtained		Created GIS-based models in publications	Modeling drinking water distribution systems; computer applications, modeling and computer-assisted real-time data acquisition and control methods

Notes: All names are pseudonym; SNRE—School of Natural Resources and Environment; SPH—School of Public Health; GIS—Geographic information system; ArcView—method of look at digital map; HEC—hydro engineer C.

using a process video technique (Krajcik et al., 1988). During the modeling session, the researcher remained silent unless asked to explain something.

On the next day, the researcher spent about 50 min showing the process videotapes to the participants and asking them to articulate rationales in the modeling episodes. The researcher only showed some episodes of the whole video, because of time constraints. If a participant could remember their rationale for what they did, it might mean that he/she had made a meaningful decision instead of just thinking randomly. This process was used by Chi and her colleagues (Chi et al., 1981, p. 123). This debriefing session was to clarify why she/he did certain activities. Questions clustered around four groups: first group of questions was about the modeling process (patterns and sequence). Sample questions include the following: How did you build the model? Could you explain your model to me? What else would you want to accomplish if you had more time?" The second group of questions included, "How did you make use of the scaffolds in Model-It? What features in Model-It helps you to build your model? Was there any limitation that restrained you from building an accurate model? Do you have any comment about how to modify the program?" The third group of questions inquired about their strategies in building their models, such as "When you were asked to build a "water quality" model, what came to your mind? Was it the whole model or part of it? How complex was it? In hindsight, what strategy do you think you used to build your model?" The fourth group of questions explored their research experience and modeling expertise. Sample questions included, "Your model looks very specific—is this related to your specific research projects? What modeling experience do you have? What tools did you use?"

Data Analysis

Description of the Process Videos. The process videos were transcribed into a text format. The tape included detailed descriptions and some verbatim transcriptions of modeling activities. Within each transcript, the unit of analysis was one "episode" during which a modeler stayed on one specific mode of the tool (i.e., plan, build, or test). An episode was thus one set of actions. For example, a user might create three relationships before he/she went to test mode, this set of actions were one episode that could be labeled as "creating relationships." At the beginning of each episode, a time mark showed when the episode started. Therefore, the duration of a user's stay at a mode could be calculated. The video tape description captured: (1) participants' use of the tool (e.g., creating a variable or a relationship, testing their model, or shifting to another mode), (2) participants' modeling practice when using the tool (e.g., making explanations, generating ideas, or seeking information), and (3) helps or supports provided by the tool or the researcher.

Data Coding and Reduction. The coding scheme incorporated four parts: administration codes (i.e., codes that help identify certain records), modeling actions (i.e., participants' use of the tool), modeling practices (i.e., participants' activities of reasoning during modeling), and scaffolds (i.e., supports or helps provided by the researcher or the tool). Administration codes, such as date, time, and period helped researchers retrieve certain records and search across the data corpus. To document the action part of the scheme, main actions of participants were identified in each mode. For example, in the plan mode, participants could use the tool to create, modify, and delete objects.

The modeling practice part of this analysis scheme was generated through an iterative process (Fretz et al., 2002). Stratford et al. (1998)'s taxonomy of modeling activities was used for a trial coding. The taxonomy-guided researchers to reframe and add modeling practices that were observed from the process videos. A refined scheme for another trial

coding was then created. The refining process was repeated until the scheme accurately portrayed the participants' modeling practices, which means the three transcribers had come to a basic agreement about the coding scheme in the description. Modeling practices were classified into six categories: planning, searching, synthesizing, analyzing, explaining, and evaluating. Under each category, several expert modeling practices were specified. The final coding scheme is provided in the Appendix.

The description of process videos was imported into a qualitative data analysis tool, Nud*ist® (Richards, 1999). Coding was based on episodes, which defined one occurrence of a modeling practice before a user switched to another one. This tool allows searching by codes and making reports that indicate the instances when modeling practices occurred. Therefore, the detailed description of a certain modeling practice in the process video could tell not only "how often" a modeling practice happened, but also "when" and "how" a modeling practice happened. For example, if we want to see how many times it happened with "stating goals" (code number code 4.1.2) during, we could enter this code and count the occurrences of this modeling practice with information on when and how it happened. By using searching and reporting commands, we obtained the data to answer such questions as "what modeling practices were most frequently used in each mode by different participants?"

To visualize how the participants used the tool and to obtain an overview of participants' activities, "mode movement charts" (Fretz et al., 2002) (see Figure 5) were created. In mode movement charts, different modes (i.e., plan, build, and test mode) are shown by different stripe patterns. The length of the stripes represents the amount of time spent in a mode. By using these stripes, mode movement charts illustrated the patterns and sequences of shifting among the three modes in each session. Because Model-It was designed purposely with three modes, the description of the modeling processes was mode-specific.

Data Synthesis. To answer the research questions, we synthesized the information from the mode movement charts, the frequency counting, and process videotape descriptions. We

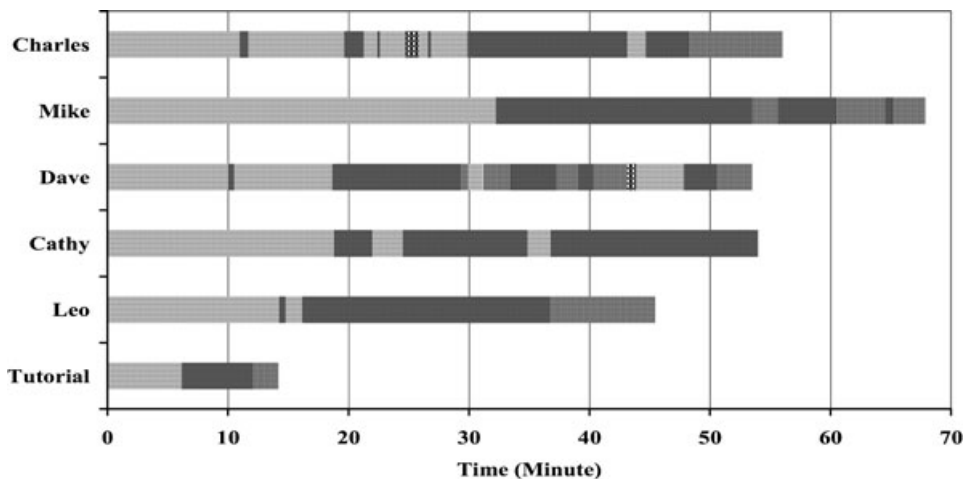


Figure 5. Experts' mode movement pattern during modeling that is in general linear from planning to building and to testing without much going back and forth. On the mode movement chart, the vertical dotted box represents activities in plan mode ■; the cross dotted box represents build mode ■; the fine vertical line box represents the test mode ■; when an expert did not know what to do by clicking and shifting between modes, it was represented by a black box with smaller white squares inside ■

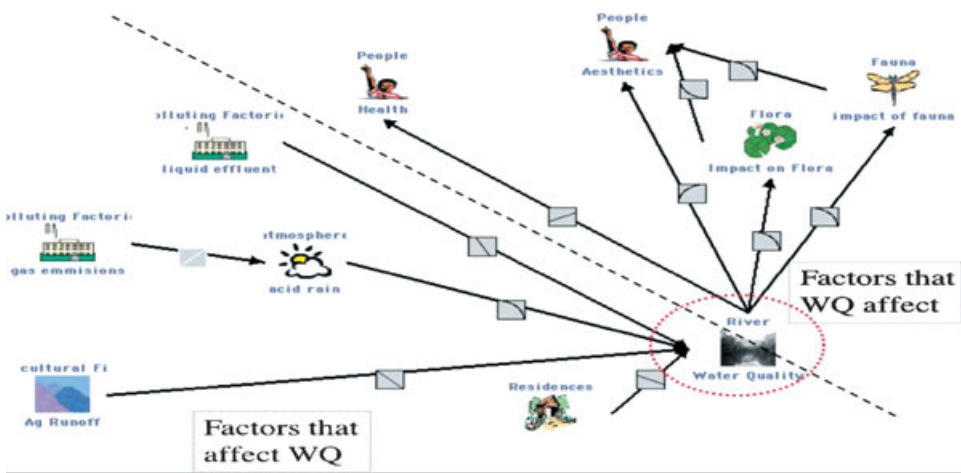


Figure 6. Leo's final model on water quality. (Color version is available on WileyInterScience)

identified the patterns and sequences of how participants demonstrated modeling practices and how they switched among the modes. We identified possible interactions among patterns of switching modes and demonstration of modeling practices. Based on the identified patterns, we generated assertions. Assertions were validated by confirming evidence from the data corpus (Erickson, 1986).

For all the water quality models, model layouts were analyzed checking for differences in model structures between participants. As shown in Figure 6, for each model, the circles identify the central variable in the model. In the water quality models, the central variable is "water quality." Dashed lines illustrate the patterns of variable groupings. Squares denote the identifying criteria for the grouping on one side of the dashed line.

RESULTS

Mode Movement

In order to obtain an overall picture of the modeling processes of experts, a mode movement chart was created to demonstrate the chronicle mode movement and duration of experts (Figure 5). To provide a comparison, the mode movement pattern for the tutorial session is also included.

Plan Mode. The mode movement chart shows that experts spent a long time in the plan mode and in general did not return to the plan mode. The longest stay in plan mode was 32 min, and Mike had only one stay at plan mode. Aside from asking questions about how to create objects or variables, the experts seemed confident about their model because there was little modification to the objects or variables once created. Experts filled in almost all the required spaces such as objects, variable names, initial values of variables as well as the descriptions of an object or variable.

Build Mode. Experts usually built all the relationships concurrently in build mode. As in plan mode, they usually filled in all the required spaces for articulation and explanation about the relationships they created. Although Charles did not fill in all the articulation boxes because of time pressure, he talked to the researcher about what he was supposed to

explain and he knew that his explanation was recorded. The longest stay at build mode was Leo and Mike (about 10 min); Leo had only one more very short stay at build mode. Detailed analysis of activities in build mode shows that once experts had created a relationship, it was rare that they would modify or delete it.

Test Mode. Experts popped up meters of all or some of the variables and ran the simulation to test their models. Charles, Cathy, and Leo had only one stay in test mode. Dave had several mode moves between build and test modes because he tried to troubleshoot a feature of the program. Mike had more than one stay at test mode because he found the program could not use a feedback loop. He had only one independent variable so that he had to break several relationships in order to make several independent variables to test the model. Except for Charles, in general, experts had plenty of time to test their models. Charles felt a considerable time pressure because he was not used to the way that the program was designed to create variables. He assigned variables to the wrong objects, then he had to delete them by switching to build mode, and then he switched back to plan mode again to continue working. That explains why he was an exception by having five moves to build mode before he actually built relationships. However, the total time (56 min) he spent in creating his model was still close to the average time of all the experts (Mean = 55 min).¹

Modeling Practices

First, the mode movement charts show that experts in general went through a more or less linear process from plan, build to test mode. Even when they switched back, such as from build mode to plan mode or from test mode to build mode, the duration was relatively short (less than 3 min). Charles was an exception as described above. However, very few of those moving backwards resulted from the lack of considering their models. For example, Dave had a very short stay in build mode before he started building relationships because he accidentally switched to build mode and deleted a variable as a trial. Therefore, the experts' activities of creating objects and variables (in plan mode) and creating relationships (in build mode) were much more focused.

Second, experts used test mode very briefly for evaluating their model. As Leo said in the debrief interview, he came to test to see how the program worked. Leo spent his last 5 min at build mode to double check all his variables and relationships. Therefore, it was not necessary for him to test the model because when he created the right variables and relationships, he knew that his model was what he expected. Overall, experts made few revisions to their models according to the testing results. Experts seemed to be able to predict their models' behaviors before they went to test them.

Modeling Practice During Plan Mode. Table 2 presents the frequency of 10 most common expert modeling practices. The most common practice was explaining why and how. Because the plan mode was the first place where a modeler began to create a model, this was the mode in which researchers would expect the users to discuss the driving question (Novak & Gleason, 2001), what kind of scenario they want to portray in the model. Experts usually stated their goals or purposes of their model at the beginning (in plan mode). For example, during his modeling process, Mike said that he was creating a model for water quality in the river system in Ann Arbor and the Midwest area. Experts elaborated their

¹ Although the experts were asked to use about 45 minutes to create their models, most of them spent a longer time.

TABLE 2
The Frequency of Modeling Practices Demonstrated When Building a
“Water Quality” Model

Modeling Practices	Leo	Cathy	Dave	Mike	Charles	Total
Planning: Stating goals	P: 1	P: 1	P: 1	P: 2	P: 1	12
	B: 2	B: 3	B:	B:	B: 1	
	T:	T:	T:	T: 1	T:	
Planning: Explaining why and how	P: 7	P: 4	P: 5	P: 8	P: 10	53
	B: 1	B: 3	B: 5	B: 6	B: 4	
	T:	T:	T:	T:	T:	
Analyzing: Elaborating objects/variables	P: 7	P: 4	P: 5	P: 3	P: 8	36
	B: 2	B: 3	B: 3	B:	B: 1	
	T:	T:	T:	T:	T:	
Analyzing: Discussing relationships	P:	P:	P: 5	P:	P:	26
	B: 5	B: 5	B: 5	B: 2	B: 2	
	T:	T:	T: 2	T:	T:	
Synthesizing: Making connection to experiences	P:	P: 3	P:	P: 6	P:	23
	B: 3	B: 1	B: 1	B: 5	B: 2	
	T: 1	T: 1	T:	T:	T:	
Synthesizing: Critiquing/interpreting test results	P:	P:	P:	P:	P:	12
	B:	B:	B:	B:	B:	
	T: 2	T: 2	T: 2	T: 5	T: 1	
Meta-cognition: Seeking information	P: 3	P:	P:	P: 4	P: 2	25
	B:	B: 3	B: 3	B: 2	B: 1	
	T: 2	T: 1	T: 2	T: 1	T: 1	
Meta-cognition: Deciding the course of action	P:	P:	P:	P:	P:	6
	B: 2	B:	B: 1	B: 1	B: 1	
	T:	T:	T:	T: 2	T:	
Synthesizing: Identifying anomalies	P:	P:	P:	P:	P:	10
	B:	B:	B:	B:	B:	
	T: 2	T:	T: 4	T: 3	T: 1	
Synthesizing: Identifying/proposing solutions	P:	P:	P:	P:	P:	7
	B:	B:	B:	B:	B:	
	T: 1	T:	T: 3	T: 2	T: 1	

Note: P: plan mode; B: build mode; T: test mode.

decisions of choosing certain objects, variables, and relationships (analyzing) with good rationale. Although they were asked to tell what they were thinking, they usually justified what they were doing. Generally, their actions were consistent with what they intended to do. They were unafraid to ask questions, as shown by the code “seeking information.” However, all the questions related to software usability. On test mode, they could still find something unexpected, but those were mostly due to the set up of their initial values of variables or usability issues that affect test results. For example, when Cathy put all the descriptions into her variable names, she found something wrong on build model when she started building relationships. Another interesting aspect is that if they found an anomaly, they usually were able to fix them immediately (identifying and proposing solution).

All the five experts confused objects and variables or factors. The following example of Dave’s experience shows how experts were confused with objects and variables:

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 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 put “new residences” as a new factor there,
oh, new object.

In the above quotes, both experts were confused between objects and factors. The reason for the confusion might be that experts did not think in terms of an object first, then its variables or factors. During a debriefing session, Cathy said that she thought about variables in her research. Objects seemed to be implicit to experts because a factor must deal with an object so that it even did not need to be mentioned. As our process video description showed, in most cases, experts simply drag an image from the image palette (Figure 1) to create an object. Experts mentioned either on process videos or interviews that they did not have images they needed on the image palette.

Modeling Practices in Build Mode. The main activities in the build mode were creating and modifying relationships. The relationship editor opened after a connection was made between two variables. Modelers used the verbal descriptions and/or graphic displays provided in Model-It to decide how to depict their relationships (see Figure 3).

Experts’ explanations were supported by evidence that ties to their experience. Although explanation is not unique to build mode, a more detailed explanation could be found in build mode (17/37 instances). Experts were asked to provide explanations about what they were thinking and doing. However, the experts provided evidence to support their explanations. Usually they would refer to their field experiences, literature, or phenomena more or less automatically. Overall, the five Ph.D. students provided 21 instances (10%) that referred to their own experience or literature when giving explanations. The arguments generally were supported by evidence. For example, the following excerpt from process video illustrates the extensive understanding by 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 do is to 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.

In the above quote, Mike created a relationship between water quality and surface—as pervious surface increases, water quality decreases. This relationship was further substantiated as: because water delivered to the river gets accelerated. He further explained the relationship as: there were many pollutants on the surface and in the sewer (oils, insecticide,

etc.); pervious surfaces help mix rain and pollutants that rush into the rivers without filtering through any soil or letting biotic organisms degrade the poisons and chemicals.

The visual representation of the model layout, textual, and graphical representations of relationship on the relationship editor helped experts keep track of their modeling processes. For example, Cathy said that she was a visual person, and so the relationship editor made it easier for her to create and see the relationship. Frequently, experts stopped, looked at the variable icons, and adjusted the position of variable icons to form certain patterns so they could examine whether their models were what they expected to build.

Modeling Practices in Test Mode. The dynamic meters and colored line graphs seemed to help experts when they were testing their models. According to their comments, experts liked the multiple representations of relationships demonstrated by meters and graphs on test mode. However, as previously mentioned, test mode seemed to be unimportant for experts because they carefully planned their model and frequently checked their variables, relationships, as well as the pattern of how variables icons were arranged on model layout. However, while in the test mode, the experts tried to discover bugs in the program. On the other hand, taking less advantage of test mode does not mean that experts did not need to test their model. The reason for the lack of need of testing here, according to Leo, was that the model was relatively simple.

Characteristics of Expert Models

Model-It was developed with implicit general expectations. A driving question or scenario is expected at planning stage so that the major focus that a model is intended to represent will be articulated or elaborated. At plan mode, object and variable names are intended to identify the appropriate visible entities and their measurable traits. Object and variable description boxes should be filled in for the definition and/or explanation of a certain object or variable. The quantitative and qualitative initial value editor for variable is intended to be accurate for variables that students investigated. At build mode, the relationship editor has two intertwined functions. First, students need to specify a relationship; second, students need to give explanation to why they specify a certain relationship. In test mode, students can visualize how multiple variables work together and affect each other. Students can also link multiple representations to think through variables with different initial values and how they affect each other. Figures 6–10 present the final tested expert models.

Foci of Modeling. Although all the experts were presented with the same general task, i.e. creating a model on water quality, the experts nonetheless started with a more or less similar focus to model. In Leo's final model, he indicated his focus to be "RIVER" (object) and "Water Quality" (factor). Cathy's focus was "HURON RIVER" (object) with "Water Quality" as factor; Dave's focus was represented as "WATER QUALITY" (object) and "Nutrient Level" as factor; Mike's focus was represented as "RIVER" (object) and "Water Quality" as factor. Charles's focus was represented as "SURFACE WATER" (object), and "Biological Pollution" and "Nonbiological Pollution" as factors. As shown, with the exception of Dave who inappropriately perceived Water Quality as an object, all other experts perceived water quality as a property of a specific object, such as a river. We perceive this feature in experts' models to be the ability to operationally define the task. Even in Dave's model, although water quality should not be an object, he nonetheless elaborated water quality into a specific aspect—nutrient level.

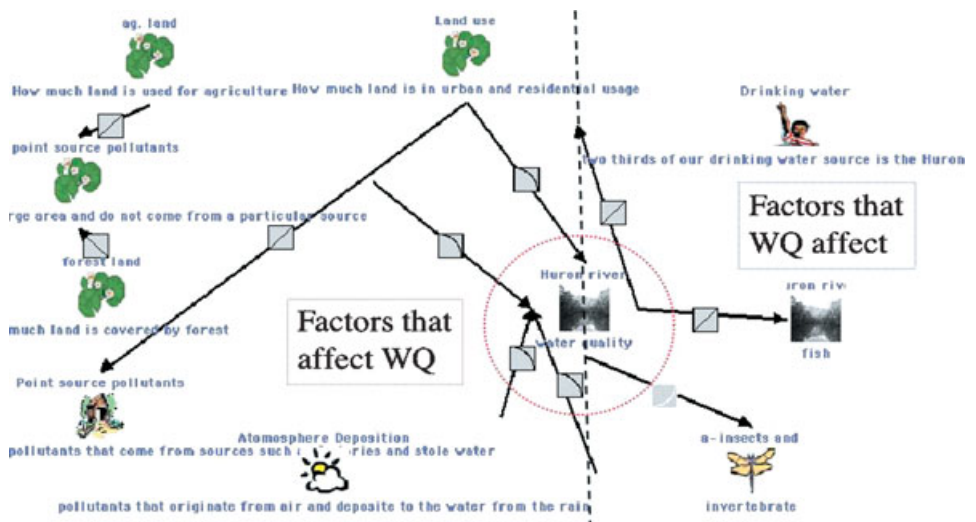


Figure 7. Cathy's final model on water quality. (Color version is available on WileyInterScience)

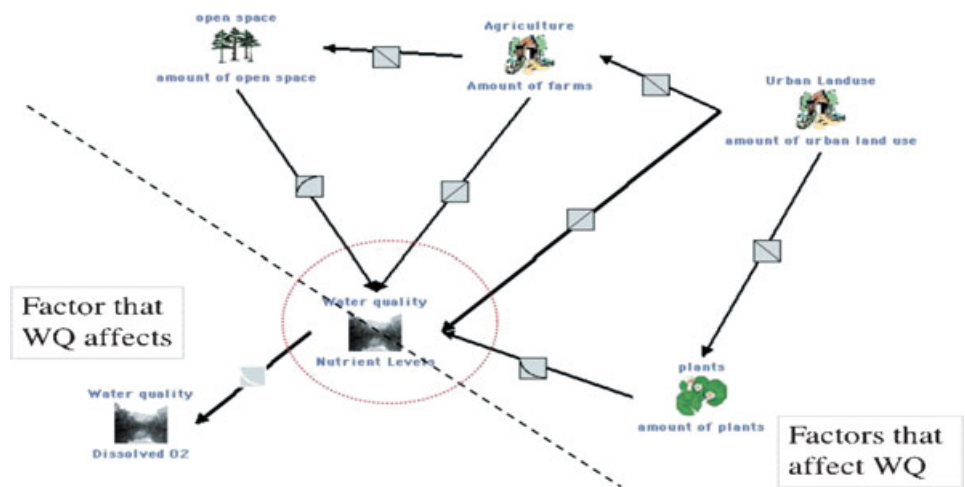


Figure 8. Dave's final model on water quality. (Color version is available on WileyInterScience)

Objects/Factors. From the expert models in Figures 6–10, as well as the “Think Aloud” transcripts, all expert models appear to demonstrate a common feature—clustering. During the planning stage, experts organized their variables in a pattern as if they had all the relationships between variables in their mind. Around the driving question or focal object (e.g., water quality), there appear to be two separate clusters of objects/factors as indicated by the dashed lines in the expert models in the figures. One cluster contains the objects/factors that affect water quality, and the other cluster contains objects/factors that water quality affects. For example, in Figure 6 of Leo’s model layout, it shows that the center of the model is the factor: RIVER-water quality. Factors that water quality affects were grouped on one side of the dashed line and factors that affect water quality were grouped on the other side of the dashed line. In presenting the experts models (Figures 6–10), we have indicated our analysis of the models. The squares with texts and the circles and dashed lines are added by the researchers for annotation.

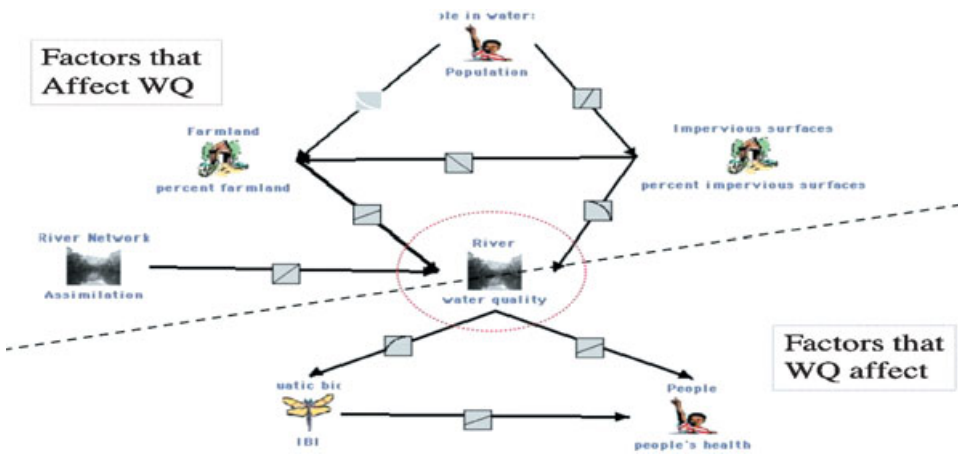


Figure 9. Mike's final model on water quality.(Color version is available on WileyInterScience)

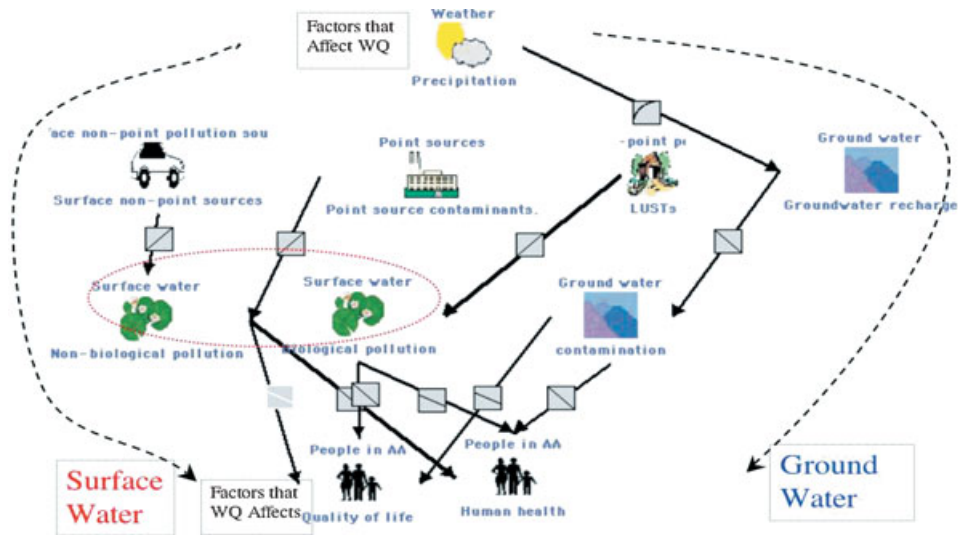


Figure 10. Charles's final model on water quality. (Color version is available on WileyInterScience)

Table 3 presents sample objects and factors in the expert final models. From Table 3, we can see that most objects/factors that water quality affects are related to living organisms, such as people and their health, and impact on flora. Most objects/factors that affect water quality are associated with industries (e.g., point source pollution), agriculture (e.g., farm land), and urban development (e.g., residence). Experts used technical terms such as point source pollution, LUSTs, and ground water recharge. It is clear that the included objects/factors affecting water quality reflect the expert's specialization in natural resources and public health. In terms of initial values assigned to the factors, only two experts assigned initial values to the factors, and the initial values tended to be around the middle points (e.g., medium).

Relationships. Table 4 presents precise and accurate sample relationships expressed in the expert models. With the exception of Cathy, all experts provided a clear justification

TABLE 3 Objects and Factors in Mike's Models

Cluster	Objects/Description	Factors (Initial Value) ^a
	Objects/factors that WQ affects	
Mike	People	People's health (between medium and high) (medium)
	Aquatic biota	IBI (high)
	Objects/factors that affect WQ	
Mike	River network	Assimilation (medium)
	Farmland	Percent farmland (50%)
	Impervious surface	Percent impervious surface (30)
	People in watershed	Population (50)

^aModel-It sets default initial value for factors to be medium.

of the quantitative relationships using “because . . .” statements. Cathy justified by talking about the required description; she skipped those fields she needed to fill in and actually put her description of objects in the field of object names. That explains why her model had very long names. She did not fill the descriptions due to time constraints.

DISCUSSION

In this section, we summarize major findings that contribute to new knowledge, and make sense of the findings by relating them to the literature. We also discuss implications of the findings for model-based science teaching and learning using Model-It.

First, we found that experts started modeling with an operationally defined focus, and then proceeded with planning, building, and testing models in a linear sequence. To begin building models, experts stated a clear focus expressed as an object (e.g., RIVER) and a factor (e.g., water quality). At the plan mode, experts spent long time thinking through the entire model. They considered objects, variables, and relationships and predicted the model's performance in their minds before they put their ideas in action, which resulted in their mode movement of modeling processes to be linear overall. As discussed in the introduction section, current literature on Model-It is limited to novices' cognitive reasoning processes involving Model-It (Fretz et al., 2002; Jackson et al., 1996; Spitulnik et al., 1998; Stratford et al., 1998), and modeling processes using Model-It as an inscription tool (Wu, 2002). Our first finding summarized above contributes to the current literature by revealing the linear mode movement pattern of experts' modeling practices. Because this linear mode movement pattern has not been reported in the literature in novices' modeling practices, the lack of linearity in novices' mode movement could be considered as an indication of the lack of modeling expertise.

The above finding raises an important question about the nature of modeling. It appears that the experts simply represented their mental models of water quality in Model-It; little revision of models took place during modeling, despite of the intention of Model-It for modelers to constantly test and revise in order to construct new models. We think modeling using Model-It, as well as any computer-based modeling tools, involves problem solving, and the person's ability to solve a problem depends on both the nature of the problem and the domain knowledge he/she possesses. Research has shown that problem-solving abilities depend on whether or not the problem is well structured or ill structured (Fortus, 2005;

TABLE 4
Relationships in the Mike's Model

Expert	Relationships ^a
Mike	<ol style="list-style-type: none"> 1. (As) RIVER NETWORK—assimilation (increases) RIVER-water quality (increases) (about the same) (BECAUSE) the river is able to reduce the harmful effects of pollutants in the water 2. (As) PEOPLE IN WAERSHED—population (increases) FARM- percent impervious farmland (decreases)(less and less) (BECAUSE) further population increases result in large decreases in farmland 3. (As) PEOPLE IN WAERSHED—population (increases) IMPERVIOUS SURFACES —percent impervious surfaces (increases)(a lot) (BECAUSE) new residents demand same conveniences and services, resulting in new construction 4. (As) IMPERVIOUS SURFACES—percent impervious surfaces (increases) FARM—percent farmland (decreases)(about the same) (BECAUSE) because impervious surfaces tend to replace farms 5. (As) FARM—percent impervious farmland (increases) RIVER-water quality (increases) (a little) (BECAUSE) the land is not going toward subdivisions, but farmers can be both good and bad to rivers. [Note: There was no "remain the same" option in the program.] 6. (As) IMPERVIOUS SURFACES—percent impervious surfaces (increases) RIVER-water quality (decreases)(more and more) (BECAUSE) water delivery to the river is accelerated and potential for pollutions is heightened 7. (As) RIVER-water quality (increases) AQUATIC BIOTA—IBI (increases) (less and less) (BECAUSE) animals are able to tolerate some pollution but not extreme levels 8. (As) RIVER-water quality (increases) PEOPLE—people's health (increases) (a little) (BECAUSE) they enjoy cleaner water and cleaning is easier 9. (As) AQUATIC BIOTA—IBI (increases) PEOPLE—people's health\ (increases) (a little) (BECAUSE) people sometimes eat fish from the river

^aRelationships are in the following predefined syntax: (As) OBJECT1—factor1 (increases) OBJECT2—factor2 (increases or decreases) (to a certain degree such as "a lot") BECAUSE. . . OBJECT1—factor1 and OBJECT2—factor2 can be variables of the same object or not. A model—builder creates the relationship by dragging an independent variable to another independent variable.

Shin, Jonassen, & McGee, 2003). According to Jonassen (1997), well-structured problems (a) present all elements of the problem, (b) are well defined with a known solution, (c) involve a limited number of related concepts, rules, and principles, (d) possess correct, convergent answers, and (e) have a preferred, prescribed solution process. On the other hand, ill structured problems (a) fail to present one or more problem elements, (b) have vaguely defined or unclear goals and unstated constraints, (c) possess multiple solutions, solution paths, or sometimes no solutions at all, (d) possess multiple criteria for evaluating solutions, (e) represent uncertainty about which concepts, rule, and principles are necessary, (f) have no explicit means for representing the problem and determining appropriate actions, and (g) require learners to make judgment about the problem and problem solutions. Based on the above criteria, the modeling task on water quality in the present study certainly qualifies for an ill structured problem, thus represents an authentic modeling situation. However, although solving well-structured and ill structured problems requires different sets of skills, domain knowledge is a significant predictor of both well-structured and ill structured problem-solving abilities (Shin et al., 2003). Therefore, the difference between well-structured and ill structured problems is not absolute, but only in degree, i.e. depending on the degree of domain knowledge. A problem may be more well structured or more ill structured depending on a person's domain knowledge. In the present study, although the participants all possessed advanced domain knowledge because they were all Ph.D. students in water resources and management related fields, their models and modeling practices of water quality nonetheless varied considerably (see discussion later), indicating that they were not simply "copying" a normative mental model into Model-It for the purpose of testing the tool; rather they were attempting to solve an ill structured problem. Obviously, the modeling task might be more well structured for the participants, but more ill structured for middle school students. Because we consider well-structured and ill structured problems differ only in degree, and more importantly are relative to the amount of domain knowledge, as middle school students' domain knowledge increases, their perception of the problems should resemble more and more that of the participants in this study.

No matter it is an expert or novice solving well-structured or ill-structured problem, the need to represent the problem using a tool, i.e. Model-It, is the same. One major function of computer modeling is to facilitate modelers to represent their mental models in relation to the problem task. Simon (1981, cited in Jonassen, 2003) claimed that "solving a problem simply means representing it so as to make the solution transparent" (p. 153). While both qualitative and quantitative representations of a problem are necessary (Jonassen, 2003), it is the qualitative representation that is usually weak in novices as compared to experts (Chi et al., 1981). Qualitative representations (a) help to explicate information that is stated only implicitly in problem descriptions but is important to problem solution, (b) provide preconditions on which quantitative knowledge can be applied, (c) support construction of quantitative knowledge not available initially, and (d) yield a set of constraints that provide guidelines for quantitative reasoning (Ploetzer & Spada, 1993). Therefore, although building and testing new conceptual models are important for developing modeling expertise, appropriately explicating current conceptual models in relation to a new problem as demonstrated by the participants in the present study also exhibits important characteristics of expertise.

The finding of the linear mode movement pattern we found in experts' modeling practices involving Model-It could indicate that the experts perceived the problem task as being mostly well structured. Fortus (2005) found that, when solving physics problems, experts who were physics professors and former high school physics teachers with advanced education in science education solved well-defined Newtonian mechanics problems in a linear sequence from representing problems, constructing or strategizing problem solutions, formulating

algebraic equations, calculating numerical values, and evaluating solutions. Physics professors particularly perceived the problems to be typical textbook type problems that required little strategizing or going back and forth trying. In other words, they have developed already some kind of automated sequence in solving those problems. Fortus (2005) further found that most experts were unable to solve ill-defined problems, and their problem-solving sequence for ill-defined problems contained numerous back-and-forth movements. In our present study, water quality task could have been perceived by the participants as more a well-defined problem for the participants, which could explain why their modeling practices followed a linear pattern. Because the participants in the present study possess extensive and highly integrated bodies of domain knowledge, they could recognize the underlying structure of domain problems (Alexander, 2003a; Anderson, 1993; Bransford et al., 2000; Chi et al., 1981, 1988). However, for middle school students for whom Model-It was originally intended, water quality may not be a well-defined problem, because of the students' inability to perceive all the problem variables and solution states. It is unknown what the mode movement would be for experts when they are presented a mostly ill-defined problem, which necessitates further research.

The implication of our first finding stated above is significant. In order to help middle school students develop expert modeling practices, we need first of all to identify their domain knowledge. Based on their domain knowledge, we next need to plan a series of modeling tasks that are consistent with their domain knowledge and also form a developmental trajectory from well-defined problems to ill-defined problems. Because we can anticipate that different students may have varying domain knowledge, advanced students may be able to start with ill-defined modeling problems. This gradual progression from well-defined problems to ill-defined problems in developing expert modeling practices is consistent with the call for authentic scientific inquiry by AAAS (1993) and NRC (1996). It is also consistent with the project-based science-learning approach (Krajcik, Czerniak, & Berger, 1999).

Second, we found that the most common practice during the plan mode is "explaining why and how" by providing well-supported arguments about why the experts were considering certain objects, variables, and relationships; most common modeling practices during the build mode are building and elaborating relationships with accurate and convincing evidence; and most common modeling practices during the test mode are visualizing the changing patterns of variables through multiple meters. Because the above modeling practices of experts have not been reported in the literature, this second finding contributes to the current literature by revealing what were the typical experts' modeling practices during each of the modeling modes using Model-It.

This second major finding suggests that experts may be using evidence-based reasoning. Providing adequate justification in planning and building can reduce time needed for testing and revising models, which is an indication of advanced problem-solving strategy (Bransford et al., 2000). For example, when solving mathematics problems, "experts are more likely than novices to first understand problems, rather than simply attempt to plug numbers into formulas" (Bransford et al., 2000, p. 41). This feature may also be an indication of experts' use of meta-cognitive skills. Because students may be unequipped with the needed evidence-based reasoning and the meta-cognitive/self-regulatory strategies (Winne, 1995), and individuals' practices are determined by their knowledge base and the strategies they employ (Guthrie, McGough, Bennett, & Rice, 1996), the implication of this second finding is that teachers should be aware of students' reasoning strategies in addition to their domain knowledge, and provide progressive scaffolding using Model-It to develop in students' expert modeling practices by using evidence-based reasoning and meta-cognitive strategies. As found in previous research, novices usually attend to different aspects of

problem-solving tasks than experts (Bransford et al., 2000), we need to highlight the importance of justifying relationships during modeling using Model-It and help students shift their focus from nonessential aspects of models to essential relationships of models.

Third, we found that factors in expert models are clustered. Experts tended to group things affecting water quality in one group while factors water quality affect in another cluster. Experts' final models were highly specialized, reflecting their specialization of study. This feature of expert models also contributes to the literature because there is no current literature on the structural characteristics of models, particularly experts' models, created using Model-It.

The above finding is consistent with previous research in other domains showing that experts were unique in the way they organize concepts in a certain domain (Anderson, 1993; Bransford et al., 2000). Expertise is specific to a domain (Alexander; 2003b; Hatano & Oura, 2003). The experts in this study were advanced doctoral students in natural resources management and public health; they possess strong domain-specific knowledge. Given the structured modeling processes and scaffolds, such as the relationship editor in Model-It, we should expect students to construct the kind of model structures like the experts'. Further, the strategy of clustering related concepts together should help students to be more aware of the hierarchy of domain knowledge. In this way, novices will be able to deepen their understanding of the domain. To facilitate students build expert-like models, we may consider providing examples of models with different degrees of structural characteristics. This way, a progressive approach to scaffold students from poorly structured models to highly structured models like the experts' can be taken.

Fourth, we found that experts had difficulties in differentiating objects and variables. As one expert stated in the interview session, objects were implicit to them so that they mainly thought about variables when creating a model. This difficulty does not mean the experts misunderstood the task, or did not have a good understanding of the problem solutions. This difficulty was due to the fact that Model-It adopted a different convention system than those they were used to. Using a new tool like Model-It entails getting familiar with the new conventions. This finding suggests that modeling using Model-It essentially involves two distinct types of expertise: (a) domain knowledge—knowledge on the content related to the problem and (b) inscription knowledge—knowledge on how to use the tool. Although the participants were experts in terms of their domain knowledge, they were essentially novices like middle school students in terms of their familiarity with Model-It. Modeling tools like Model-It provide both cognitive constraints and affordance (Jonassen, 2003). It could be true that Model-It constrained the expert participants' thinking because different conventions (e.g., objects, factors, and variables) and structure (e.g., three sequenced modes from plan to build to test) were adopted in the design of Model-It. However, if a learner is tuned to the properties of the tool, the learner can potentially gain greater cognitive affordance (Jonassen, 2003), which is the intention of Model-It. Modeling tools intend to shape thinking, provided that the learners are willing to adapt to the new way of thinking (Brown et al., 1993). This fourth finding contributes to the literature by demonstrating how technology and its associated conventions may form a new dimension of modeling expertise. Expertise in technology itself may be independent from expertise in domain knowledge, thus experts in domain knowledge may not be necessarily experts in technology know-how, which is the case for the participants in the present study. Thus, the implication of this fourth finding is that developing modeling expertise in novices using Model-It needs to consider to both domain specific knowledge and technological know-how. We need to give sufficient orientation to students on the conventions adopted in Model-It and make them aware how the conventions are different from what they are used to. In this way, an adaptation into Model-It may gradually take place.

Finally, we have also noticed variations in experts' modeling processes and characteristics of final models. This finding suggests that different levels of scaffolding are necessary in modeling, and this could be incorporated into newer versions of Model-It. Vygotsky (1978) proposed two possible levels of performance by students: the maximal level of performance with ideal scaffolding and a lower level of performance without scaffolding. Fischer and Bidell (1998) further elaborated on this general position by positing three levels of students performance: (a) the functional level (i.e., the level at which they perform when working independently), (b) the optimal level with modeling (i.e., where some support is offered), and (c) the scaffolded level (i.e., where considerable support is offered). Although the scaffolded level demonstrates the highest level of performance a person is capable of, typical unsupported performance usually falls short of this mark. More often, novices and even experts perform at functional or at most optimal levels due to less ideally structured tasks, learning environment, and student affective factors (Fischer & Bidell, 1998).

For example, it may be helpful for some novices during modeling by discussing relationships, critiquing, and evaluating modeling similar to what experts did in our study. In addition to scaffolds built in Model-it, teachers or peers can also be scaffolding sources. Most experts simply dragged images from the image palette to create their objects, but some of them commented that they could not find images they needed. Therefore, more images relating to students' experiences can be beneficial to some novices. More familiar images may also motivate students, particularly when they can upload their own images. A form or table built in the software that demonstrates the hierarchical structure of a model might also help students to design a model in the way that is similar to that of experts. Concerning scaffolds from teachers, probes are usually helpful. For example, when the students specify objects or factors, teachers may prompt students to explain or justify their decisions. We have to acknowledge that computer-based modeling is also new to teachers. They may also need to experience the transition from novice to expert using Model-It.

In conclusion, this study identified some interesting features of expert models and modeling practices using Model-It. We found out that the experts' modeling processes followed the linear sequence built in the modeling program without moving back and forth. They specified their goals up front and spent a long time thinking through an entire model before acting. They specified relationships with substantial elaboration and explanation. Further, factors (i.e., variables) in expert models were clustered and represented by specialized technical terms. We believe the above findings reflected both the constraints and affordance of the modeling tool, Model-It. The above findings should inform instruction on improving novices and young student modeling practices. Further research on expert modeling practices using Model-It with less familiar domains is necessary. We hope the study is of interest to science educators, technology, and curriculum developers, science teachers as well as policy makers.

APPENDIX. EXEMPLAR CODES

I. Modeling Actions, Related Scaffolds, and Modeling Practices

Creating a Variable. Clicking the “new variable” button (1) to pop up the variable editor (2); locating the object that the variable attaches to from the drop-down menu (3); filling the variable's name (4); deciding the variable range as “text” (default) (5); deciding the initial value at “high/medium/low” by changing the position of the slide (6); filling the description in the articulation box (7) and clicking “OK” to dismiss the variable editor (8).

Scaffold: Variable editor

Modeling practice: Analyzing

Creating a Relationship. Clicking on the “relationship” button (1); clicking on a variable icon (this one becomes an independent variable) (2) and dragging to another variable icon (this one becomes a dependent variable) (3); (on the popped-up relationship editor) defining how the dependent variable would change (increases or decreases) (5) with the increases of the independent variable and how much it changes (i.e., about the same; a lot; little by little; more and more, or bell curved) (6); the relevant graph will show up (7); filling in “because statement” on the statement window (8); clicking “ok” to dismiss the relationship editor (9).

Scaffold: relationship editor

Modeling practice: Analyzing

II. Modeling Practices

Planning includes statements or actions in which modelers identify important components of phenomena they are going to model; decide relationships, patterns that variables are going to be connected, or in which they attempt to predict on their model’s behavior.

Stating goals: Modelers decide what their driving question and subquestions, e.g., how clean is the stream in my community; does street runoff affects the water quality of the stream? Modelers articulate what kind of model they should have, e.g., I want a simple model; I want the model to be as complex as possible to include all the factors that I have.

Elaborating objects/factors: Modelers talk about/share ideas on the meanings of objects/factors, fill in description factors/objects boxes; state what objects/factors are relevant (or not relevant) to their driving questions or modeling goals; they talk about factors’ initial values.

Analyzing involves modelers’ statements or actions to decompose the large system that they are going to model into subsystems or components. The purpose is selecting the appropriate objects, factors, and relationships to reflect the most important characteristics of the model.

Seeking information includes talking and actions of getting more inputs in terms of any questions modelers have when they are creating models.

Synthesizing includes statements or actions related to viewing the content, behavior, or form of a model as a whole, or to making connections between previously unconnected ideas.

Elaborating relationships: Modelers state in a considerate manner about correlation or cause and effect relationships. For example, one pair of relationships modelers decided to delete the relationship between biological contaminants and ground water quality because there are not as many biological contaminants in ground water.

Making connections: Modelers make explanation or argument with the support from their experience or what connections they have learned, e.g., I did not find the pH value changed much from 7 in our investigation so that it is not the major factor that affects water quality.

Evaluating includes statements and actions in making judgment of the quality of models.

Identifying anomalies: Modelers have some unexpected findings. For example, one modeler found that he could not change the slide bar in the meter of dependent variable. Another modeler found that when acid rain increases water quality did not change that

much, as he predicted. A third modeler found that the colorful graph line of one factor does not show up because this one's initial value was set the same as another factor's. A fourth modeler found that when he runs his model nothing happened.

Critiquing/interpreting results: Modelers make comments on the test results when they run their models, such as “when critiquing/interpreting turbidity goes high, water quality goes down. . .,” “it’s working. . .,” and “. . . something is wrong here. . .”.

Identifying/proposing solutions: Modelers suggest ways to correct anomalies. “I know, X goes down because we have the identifying/proposing relationship going the wrong way.”

Meta-cognition was demonstrated by actions and statement that tie to the awareness of progression. For example, modelers state what they are going to do next, e.g., “I will go to build mode because I have already had enough factors.”

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