EXPLORING MIDDLE SCHOOL SCIENCE STUDENTS' COMPUTER-BASED MODELING PRACTICES AND THEIR CHANGES OVER TIME

by

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DEDICATION

For My Father,
Fuchun Zhang,
A farm worker, who was physically disabled by cold weather and suffers all the time, but raised me and my two sisters without applying for any government support.

For My Mother
Guiqing Gao,
A housewife most of the time, who is smart but was not able to finish her elementary school for being born to a poor family. She did not expect me to go to college given the economic situation of my family. She predicted that I might go overseas to get my PhD after I went to graduate school in Beijing.
I miss you, too, Mom!

For My Wife,
Dr. Feifei Wang,
Who continually encouraged me in this work, undertook most of the housework, and went to bed most of the time without me. Her love suffused our everyday routine life.

For My Daughter,
Wendi Zhang,
Who has been luckier than her father to be born to a family with sufficient support for your growth. It is also a responsibility of yours to improve the friendship between Chinese and Americans.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

CHAPTER I

INTRODUCTION

> " The object of our research (research in math and science classrooms) was the integrated documentation of not just the behavious social events that might be recorded on a videotape, but also the participants' construal of those events, the memories, feelings, and actions invoked, and the mathematical/scientific and social meanings and practices which arose as a consequence" (Clarke, 2001, p. 2).

Consistent with the opening citation about how to conduct research in science classrooms, this study explored the computer-based modeling practices of middle school students who worked collaboratively in a project-based science classroom environment. The research questions were: a) What modeling practices do middle school science students demonstrate during their initial computer-based modeling? b) How do middle school science student modeling practices change over time? and c) How does the design of the classroom learning environment facilitate the development of student modeling practices?

A model can describe scientific phenomena; it allows scientists to formulate and test hypotheses as well as build and justify explanations of natural phenomena. Constructing, testing, and evaluating models, therefore, is central to scientists' daily practices (Clement, 2000; Latour, 1987; Penner, 2001). Engaging students in scientific practices such as modeling provides a context for students to construct knowledge, and integrate content, inquiry and epistemological understanding of science (Clement, 2000; Gobert & Buckley, 2000; Penner, 2001; Spitulnik, Krajcik, & Soloway, 1999; Stratford, Krajcik, & Soloway, 1998; White & Frederiksen, 1998).

Given the potential benefits of modeling in science learning, it is necessary to design, enact, and conduct research on using modeling in science classrooms. Detailed, descriptive, and explorative research is important to provide an empirical account of the nature of student modeling processes as well as practices and how the practices might be associated with content learning, inquiry, and epistemological understanding of science. The purpose of this study is to provide such a description of middle school student modeling practices in two inquiry-based curricula using a computer-based modeling tool called Model-It.

Using modeling in science learning answers calls from the National Research Council [NRC] (NRC, 1996) and the American Association for the Advancement of Science [AAAS] (AAAS, 1993) to use "authentic" science inquiry in science learning. According to AAAS, the goal of science education is to help develop a scientifically literate person as "one who is aware that science, mathematics, and technology are interdependent human enterprises with strengths and limitations; understands key concepts and principles of science; and uses scientific knowledge for individual and social purposes" (AAAS, 1990, p. xvii). The above view of science learning matches the research on scientists in practice (Latour, 1987; Lave & Wenger, 1991). This science as social practice view recognizes that knowledge is constructed in a certain context, within a community of practitioners (Lave & Wenger, 1991). The power of modeling, according to this view, is that it allows students to experience scientific practices that are similar to those of real scientists (Barab & Duffy, 2000; Roth, 1998; Stratford, 1998). In the National Science Education Standards (NRC, 1996), science teachers are encouraged to "develop descriptions, explanations, predictions, and models using evidence" (NRC, 1996, p. 145). With the increasing use of computers in science and science education, computer-based programs have become a powerful way to facilitate student modeling activities (Jackson, Stratford, Krajcik, & Soloway, 1996; Penner, 2001; Windschitl, 2000).

Students face a number of difficulties in creating and using models for science learning; such difficulties include limited experience with creating and using models, and lack of advanced mathematical skills (Jackson, Stratford, Krajcik, & Soloway, 1994; Stratford, Krajcik, & Soloway, 1998; Quintana, 2001). Over the past fifteen years, numerous researchers have used computer-based modeling tools to support learners in modeling tasks (e.g., Jackson et al., 1996; Mandinach, 1989; Resnick, 1996; Schwarz, 1998; White & Frederiksen, 1998). However, few empirical studies have attempted to characterize the nature of middle school student computer-based modeling practices in supporting students to learn science. Furthermore, most existing studies (e.g. Buckley, Gobert, & Christie, 2002; Gobert, Snyder, & Houghton, 2002; Schwarz, 1998) evaluated student artifacts and pre- and post-tests as the results of learning. Very few studies (see Barab, Hay, Barnett, & Squire, 2001 as an exception) have explored the development of student modeling practices and characterized the dimensions of student learning that were involved in student modeling processes, such as student content knowledge, modeling knowledge, and metacognition. Furthermore, few studies have traced the change in student modeling practices over time.

As for past studies of Model-It, Jackson and her colleagues used a learner-centered design approach that made computer-based modeling accessible to high school students (Jackson, Stratford, Krajcik, & Soloway, 1994; Jackson, Stratford, Krajcik, &

Soloway, 1996). Stratford, Krajcik and Soloway (1998) found that the use of Model-It engaged students in a range of cognitive strategies in computer-based modeling, such as analyzing, relational reasoning, synthesizing, and testing and debugging. Spitulnik, Stratford, Krajcik, & Soloway (1998) found that Model-It engaged student in discussing and building relationships and explanation of a subject area. Singer, Krajcik, and Marx (2000) analyzed middle school students' models using quantitative and qualitative methods. They found that many models had errors in terms of inappropriate association between a variable and its object and relationships that were not relevant to the central themes. More studies are necessary to explore how middle school science students engage in modeling practices. Given that previous studies only explored modeling during one curriculum unit, more research is needed to explore the changes in student modeling practices over time. Furthermore, a consideration of the entire learning environment with different dimensions of student learning seems to be necessary in order to explore what is associated with student modeling practices.

Importance and Contributions

Given the importance of modeling in science learning, little is known about the nature of middle school student modeling practices. As Suchman (1995) argued, with regard to scientific workplace practices, "The way in which people work is not always apparent. Too often, assumptions are made as to how tasks are performed rather than unearthing the underlying work practices" (p. 1). It seems that this is true for characterizing student modeling practices as well. Further, engaging and making sense of modeling practices that are similar to the practices of scientists takes times (Latour, 1987; Roth & McGinn, 1998). Therefore, the earlier students engage in modeling practices, the better for them to develop a "habit of thinking" (Bransford, Brown, Cocking, Donovan, & Pellegrino, 2000; Wiggins, 1989). Knowledge of student learning processes involving models and modeling should provide guidance on how to teach and how to create curricula, software, and resources for teaching models.

This dissertation provides a detailed, descriptive analysis of middle school student modeling practices in a purposefully engineered classroom learning environment following a "design-based research" approach (Brown, 1992; Collins, 1992; 1999; in press; The Design-Based Research Collective, 2003). It contributes to the field in three ways. First, it provides a detailed description of middle school student computer-based modeling practices and their changes over time. Second, it characterizes the major dimensions of student learning that are associated with the modeling practices. Lastly, it creates a profile of the computer-based modeling and science-learning environment so that researchers, curriculum and software developers, and teachers can use the results to better design such environments. The results will help educational researchers, curriculum and software developers, and teachers in designing better informed curricula and class learning environments, especially the modeling program as emphasized according to the design-based research approach.

Definition of Major Terms

Given the present literature about models and modeling, the following eight dimensions seem to be involved in student learning from modeling. They are modeling actions, modeling practices that describe what students do and talk during modeling and how those actions and conversation reflect the practices of scientists. Content knowledge is the knowledge of a science subject domain that a model is intended to describe.

Modeling knowledge reflects the nature of modeling as the central of science. Inquiry experiences provide rich empirical experience about a scientific phenomenon that is described in a model. Metacognition is a dimension that is related to learning in general. It might be specific in terms of the modeling context using Model-It. The modeling integrated curricula allow teachers to implement their ideas about what to teach and how to teach. Since students learn from interaction between each other, teachers, and researchers, the social dimension of learning reflects this characteristics. In the following section, I discuss each of the eight dimensions, which comprise the theoretical framework of this dissertation.

(1) Modeling actions: Modeling actions are what students do during modeling processes. When constructing and evaluating computer-based models, modeling actions usually include specifying what to model, deciding on variables, defining relationships, testing and debugging, and sharing and communicating the products with others (Mandinach, 1989; Stratford, 1996; Zhang, Wu, Fretz, Krajcik, & Soloway, 2001).

(2) Modeling practices: Modeling practices are ways of thinking demonstrated by a series of modeling actions and conversations that help modelers to complete modeling tasks, make sense of what they are doing, and communicate their ideas with others. In this dissertation, middle school students used a computer-based modeling tool called Model-It. It is created by hi-ce (Highly Interactive Computing in Education) program at the University of Michigan (Jackson et al., 1994). According to the literature, the major categories of modeling practices include planning, analyzing, building or constructing, reasoning, interpreting, synthesizing, evaluating, and critiquing models (Dunbar, 2000; Latour, 1987; Roth & McGinn, 1998; Schank, 1994; Stratford et al., 1998; Wu, 2002). A

more detailed explanation of these modeling practices is provided in Chapter two. They reflect the cognitive processes through modeling actions and conversations between students. Such modeling practices are intended to improve student higher-order thinking skills, such as analyzing, synthesizing, and evaluating as defined by Bloom and his colleagues (Anderson & Krathwohl, 2001; Bloom, Mesia, & Krathwohl, 1964; Hopson, 1998).

(3) Content knowledge: Content knowledge is what students think with and think about when they create or use models for science learning purposes. Instructors of models and modeling need to consider what students bring to their learning process (Linn, diSessa, Pea & Songer, 1994); students cannot build models if they have no associated content knowledge. For example, if students are building or using a model of physics to learn about force and motion, they have to have some basic content knowledge, such as what force is and what motion is, in order to design experiments, make observation, make sense of a simulations, and create conclusions. When making use of their basic content knowledge in modeling, students make connections between concepts, thus deepening their understanding of the content (White, 1993). In this study, student modeling practices are based on their content knowledge built from their investigation experiences in water quality and decomposition.

(4) Modeling knowledge: Modeling knowledge refers to student epistemological understanding of models and modeling (i.e. the nature of models, the nature of modeling, evaluation of modeling, and the purpose/utility of models) (Gobert, Snyder, & Houghton, 2002; Schwarz, 1998). Student modeling knowledge can be considered as the what, why and how behind student modeling behaviors and reasoning about models and modeling. It

is argued that modeling knowledge affects student use of models as representations of scientific phenomena for their explanatory power (Gobert & Discenna, 1997). For example, if a student only thinks about relationships between variables without thinking how each relationship is related to the model as a system, the student might not come to the understanding of a model as a whole system with interrelated relationships (Grosslight, Unger, Jay, & Smith, 1991; Schwarz, 1998). On the other hand, building and modifying models also develops and modifies student modeling knowledge (Carey & Smith, 1993; Cartier, 2000; Gobert et al., 2002; Grosslight et al., 1991; Schwarz & White, 1998).

(5) Inquiry experiences: Inquiry experiences refer to the process of designing, carrying out investigation, analyzing data, and making conclusions. As a subsequent process, modeling involves describing a phenomenon and possibly making predictions using a model. In order to be able to do this, students need to analyze data, interpret data, and make conclusions that make sense to them either from firsthand data or second-hand data (Krajcik et al., 1998; Novak & Gleason, 2001). Studies of scientists' work practices show that scientists need to have data first, then they use different ways to represent data in order to find patterns (Latour, 1987; Lynch & Woolgar, 1990). Modeling, thus, becomes a way to explain and predict the behavior of science phenomena. Therefore, inquiry experiences become an important knowledge base that allows model building and the use of models to serve scientists' purposes.

(6) Metacognition: Metacognition refers to knowledge of one's own cognitive processes or anything related to them (Flavell, 1976). Although metacognition is not unique in learning science through modeling, White and Frederiksen hypothesized and

confirmed that making complex science ideas (such as are found in physics) accessible to a wide range of students could be achieved by promoting student metacognition using a modeling integrated curriculum (1998). With the same intention, this study also characterizes student modeling actions and conversation during the modeling processes that revealed their metacognition and its possible changes over time.

(7) Modeling integrated curricula: Modeling is considered as an integrated part of the curricula in the study because modeling allows students to represent and develop their understandings after their investigations of water quality and decomposition. To date, there have been a variety of curricula that incorporate modeling in learning subject domains such as biology, physics, water ecology, and weather (Gobert, Snyder & Houghton, 2002; Passmore and Stewart 2002; Schwarz 2002; Spitulnik, Krajcik, & Soloway, 1999; Stratford, Krajcik, & Soloway, 1998). With explicit teaching purposes, modeling was used in a systematic way as part of the curricula. In this study, computer-based modeling naturally fit into the curricula according to a project-based science approach (Krajcik et al., 1998; Novak & Gleason, 2001).

(8) Social aspect of modeling (Collaboration): Collaboration is highlighted as one of the important dimensions of student learning because student learning occurs in a community of learners, that is, a knowledge-building community (Scardamalia & Bereiter, 1993/1994). A broad view should be used to look at student modeling practices within social constructivist view of learning. In this learning community, students make use of social, conceptual, and material resources (Roth, 1996). According to this framework, in my study, a social aspect of modeling practices refers to how students collaborate and communicate with their peers, teachers, researchers as well as other

knowledgeable individuals. For example, students can interact with a water quality expert from a water treatment plant as a guest speaker. The conceptual aspect of modeling practices refers to student conceptual understanding of the subject matter and the nature of models and modeling as scientific enterprise. The material aspect of modeling practices refers to the tool (i.e. Model-It) and other learning materials that students are able to use. The three aspects were both the backgrounds and context (learning environment) in which students perform the modeling practices. Further, in the learning environment, learning goals also guide, diffuse, and evolve through student modeling practices.

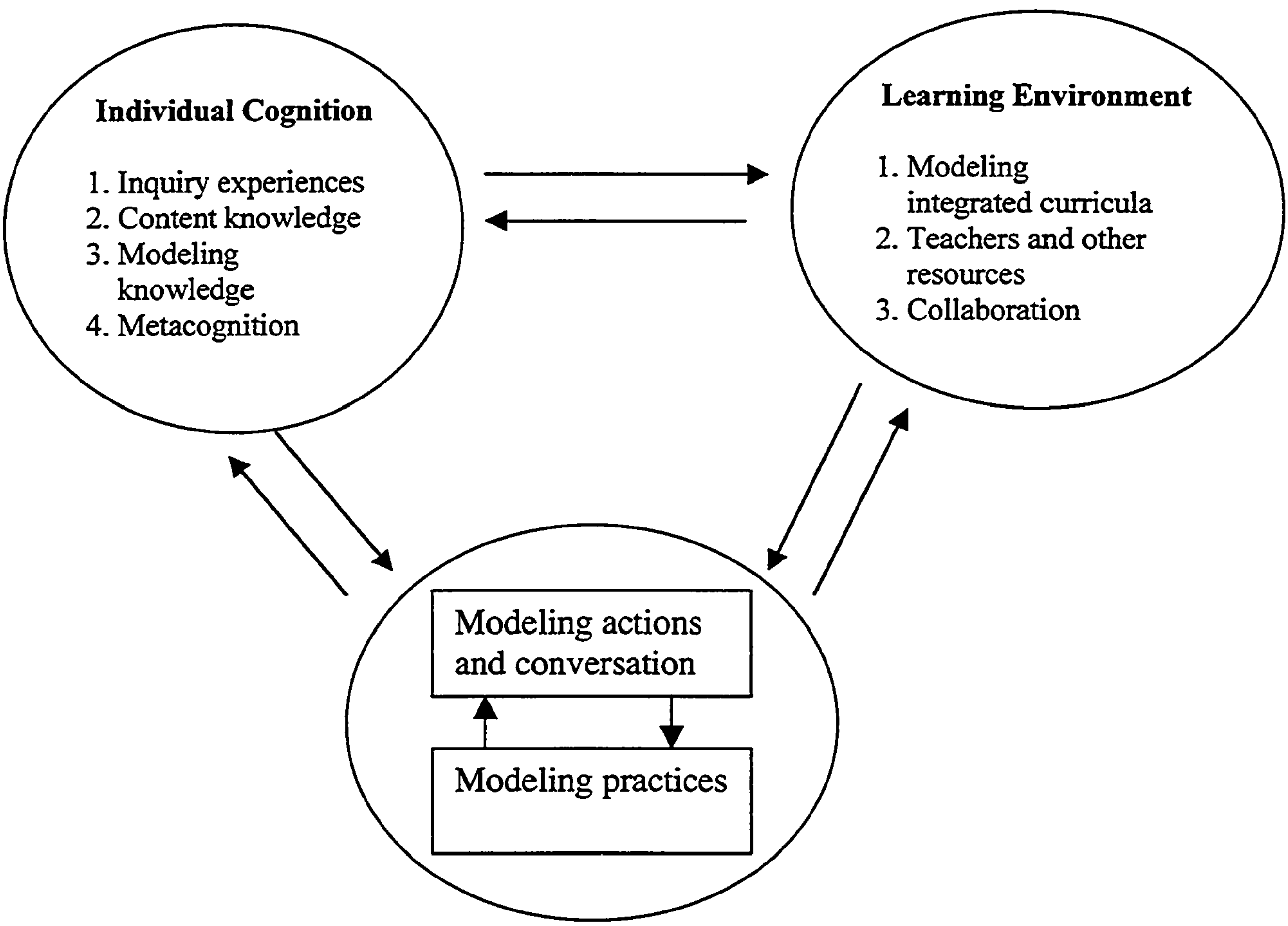

Figure 1.1 Theoretical Framework of the Dissertation

As shown in Figure 1.1, the intended theoretical framework for this research project was to situate individual cognition in a purposefully designed, computer-based modeling integrated learning environment. Individual cognition includes student inquiry experiences gained through their investigations and life experiences, basic content knowledge, and basic understanding of modeling. Modeling knowledge was not emphasized intentionally in the curricula because it was expected to occur to students during their modeling practices. According to the framework, student metecognition is also an important dimension in the study. In the constructivist learning environment, collaboration is a very important for learning as well. Individual cognition is expected to be enhanced through communication and collaboration. The curricula were certainly the important component that made student learning happen in a planned manner. Teachers, researchers, peers, knowledgeable individuals, and other resources were also very important in the learning environment. Lastly, for design-based research, the major focus of the investigation was computer-based modeling.

As the arrows show, there is a two-way interaction between individual cognition and the learning environment. Student modeling actions and conversation reflect student context-based cognitive processes (i.e. modeling practices). Student modeling practices depict how individuals' cognition converges in the collaborative learning environment. Therefore, in the framework, modeling actions and practices are between the individual cognition and the collaborative learning environment because student modeling practices involve both individual cognition and collaboration in the community of learners.

Overview of the Study

This study involved seventh graders from three science classes in an independent school in a Midwest university city. The students had just begun the study of the science domains and had limited modeling experience. Students used a dynamic, learner-centered, computer-based modeling tool, Model-It (Jackson et al., 1994; Metcalf et al., 2000), as part of their inquiry-based science curricula (Krajcik et al., 1998; Novak & Gleason, 2001). The two curricula are a water quality (WQ) unit and a decomposition unit that take place over an 8-month period of time. In this study, I explored the nature of middle school science student initial modeling practices and their changes over time when they used Model-It.

The research methodology implemented in this study followed the general guidelines of "design-based research" (The Design-Based Research Collective, 2003) that was proposed by Brown (1992) and Collins (1992). According to Collins (1992; 1999; in press), there are seven characteristics of design experiments, or design-based research. The methods of this study matched those characteristics:

1) The study was carried out in a real life learning situation: three seventh grade classrooms.
2) There were multiple dependent variables that mattered in terms of student learning. The major concern of the study was to look at how middle school students performed modeling practices using a purposefully designed modeling program (Model-It). In order to make computer-based modeling accessible to middle school students, there were several scaffolds in the program (e.g. the object editor, the variable editor, the relationship editor, and the test mode) that made computer-based modeling accessible

to middle school students (Fretz, Wu, Zhang, Davis, Krajcik, & Soloway, 2002; Jackson et al., 1996). Some other dimensions of student learning besides modeling practice emerged from our initial enactment and the modeling literature even though they were not the major foci of the first enactment. Those dimensions include student inquiryexperience, content knowledge, modeling knowledge, metacognition, and collaboration.

3) The goal for the study was to characterize the situation. I wanted to explore what happened in purposefully engineered project-based science classrooms (Krajcik et al., 1998; Novak & Gleason, 2001) when students worked collaboratively on computer-based modeling.

4) The design has been revised accordingly when more information from the enactment of the curricula was obtained. The project-based science curricula (i.e. water quality unit and decomposition unit) had been around for several years and were taught by two experienced teachers at the school (Novak & Gleason, 2001). Computer-based modeling was added to the curricula in order to highlight technology use following a project-based science approach (Krajcik et al., 1998; Novak & Gleason, 2001). Results of the first enactment of the curricula showed that students were able to perform a variety of modeling practices such as planning, analyzing, synthesizing, and evaluating with support of the scaffolds built in Model-It. However, instances of stating goals, elaborating ideas, and justifying argument were rare. Further, even though students were able to exercise certain modeling practices, it was not clear whether the modeling practices were meaningful to the students and whether they did those practices purposefully (Fretz et al., 2002 and Zhang et al., 2001).

Changes were made accordingly for the second enactment. These decisions were made according to the results of our study in the first year (Fretz et al., 2002 and Zhang et al., 2001) and through our regular group meetings with senior researchers and graduate researchers conducted the study, classroom teachers, and software programmers, supplemented by frequent emails. Short debriefing meetings were occasionally held immediately following a class.

5) Students were not isolated individuals in the classrooms; they were in a "community of learners" (Brown, 1992; Wenger, 1998). They could talk to their partners in a pair or group; they could talk to the classroom teachers, researchers, and peers from other pairs or groups; and they could check their notebook, records of investigation, and other resources.

6) The study looked at the many aspects of the design and characterized the design in practice. Instead of testing hypotheses, this study develop a qualitative and quantitative profile in order to allow the designers, teachers, and researchers to be able to understand the effectiveness of the design and obtain information about how to revise and improve the design.

7) The study involved participants who represent different perspectives in the design. University researchers were also co-designers of the learning environment, including the curricula and software; classroom teachers were also co-designers of the curricula and it was they who enacted the curricula. The above research team members also brought their expertise to the analysis of the design.

After our initial enactment during school year 1999-2000 (Fretz et al., 2002; Zhang et al., 2001), this second enactment experienced three phases (or cycles): the initial investigation of water quality and the computer-based modeling cycle during the fall season (WQI); a following investigation of water quality and computer-based modeling cycle during the winter season (WQII); and an investigation of decomposition during the spring, and computer-based modeling (decomposition unit).

The class learning environment was engineered according to project-based science principles (Krajcik et al., 1998; Novak & Gleason, 2001). The science learning approach is aligned with the constructivist view of learning (Bednar, Cunnighham, Duffy, & Perry, 1991; Brown, Collins, & Duguid, 1989; Palincsar, 1998). Learning, according to this paradigm, is not considered as individuals studying a body of predetermined concepts and facts. A learner is a member of learning communities, such as a classroom community, within which the content and meaning of science are continually renegotiated as parts of the learning process (Moschkovich & Brenner, 2000). Furthermore, the view of "learning as a historical development" (Barab, Hay, Barnett, & Squire, 2001; Lave & Wenger, 1991; Roth, 1996) suggests that in order to understand student learning with modeling, it is important to trace the history of student practices by documenting and analyzing their discourse, actions, and artifacts over time.

In this study, data were collected from multiple sources, including classroom videos, process videos, student pairs' daily models, pre-and post-interviews of target student ideas about modeling, and student science reports of their water quality and decomposition investigations in the two curriculum units. Classroom videos were from the classes in which teachers introduced models, modeling, and the computer-based modeling software; classes when students used computer-based modeling; and classes when student pairs or groups presented their models to the class and accepted comments and feedback from teachers and peers. Process videos were videos recorded using a technique (Krajcik, Simmons, & Lunetta, 1988) that captured student computer screen activities and their conversations.

The primary data sources (i.e. classroom videos, process videos, and student final models) were first transformed to an appropriate format (e.g. text, graphs) for further analysis (Erickson, 1986; Moschkovich & Brenner, 2000). I adopted the techniques that helped to trace the development of student modeling practices from their discourse, actions, and artifacts (Barab, Hay, & Yamagata-Lynch, 2001, 1999; Jordan & Henderson, 1995; Roth, 1996). The process data (i.e. classroom videos and process videos) and product data (i.e. student's final models, science reports, class presentations, and interviews) from both student initial modeling practice (WQ I) and the following modeling cycle in WQ II and the decomposition unit allowed me to look at the student modeling practices over time.

Organization

In this chapter, I have provided a rationale to study middle school student computer-based modeling practices in an inquiry-based learning environment. I have also presented the significance of this study. In Chapter Two, I review the literature on modeling as well as computer-based modeling in science learning. I also illustrate the gaps in the literature that this study could possibly fill. I detail the research methods for this study in Chapter Three. I report the results of this study in Chapter Four. Chapter Five provides discussion, implications, and suggestions for future research based on the results of this study.

CHAPTER II

LITERATURE REVIEW

In this chapter, I first review the use of models and modeling in science and science education to demonstrate their importance of learning science. Given the complexity of modeling practices, I then review the efforts in science education research that has made modeling accessible to students. After reviewing the empirical studies in using models and modeling in science education, I describe the focus of this study in relation to some of the gaps in the literature.

Models and Modeling in Science and Science Education

Science educators and educational researchers are viewing science as a dynamic process of building and justifying explanation of the social and natural world. A central means through which scientific explanations are developed is the constructing, testing, and evaluation of models (Clement, 2000; Penner, 2001). Therefore, modeling plays a central role in constructing scientific knowledge (Latour, 1987; Magnani, Nersessian, & Thagard, 1999).

In the field of science education, there is an increasing emphasis on connecting school science to science in practice (Barab, Hay, & Yamagata-Lynch, 2001; Brown, Collins, & Duguid, 1989; Krajcik et al., 1998). The reason for this is that many students have difficulties understanding science taught using traditional strategies. Traditional strategies remove knowledge from the context in which it was constructed so that learners might not find it meaningful (Letour, 1987). For example, for the question “Why is the structure of DNA a double helix?” students might have to learn the structure of DNA by rote memorization if they do not know how many alternatives scientists had considered and what evidence scientists had used to verify their findings. The drawbacks of this type of learning are three-fold. First, knowledge from rote memorization is transient because it is not meaningful to students. Second, the lack of process skills and lack of understanding makes students unable to use or acquire knowledge to carry out complex or realistic tasks. And third, students lose the opportunity to learn cognitive and metacognitive skills in order to become independent learners as well as knowledge producers (Bransford et al. 2000; Collins, Brown, & Newman, 1989).

Some researchers argued that learning is a function of the activity, context, and culture in which it occurs; that is, learning is situated. Learners become involved in a "community of practice" which embodies certain beliefs and behaviors to be acquired (Brown, Collins & Duguid, 1989; Cognition & Technology Group at Vanderbilt (CTGV), 1993; Lave, 1988). One researcher even claimed that science could only be understood through its practice (Latour, 1987). The vision of connecting school science to real science has been mentioned in several nationally recognized documents. For example, National Research Council (NRC, 2000) presents an increased emphasis on making “connections between learning science, learning to do science, and learning about science” (NRC, 2000, p. xv). One of the suggestions from Project 2061 (AAAS, 1990) is that in pre-college classrooms mathematical models and computer simulations should be used in studying evidence from different resources in order to form a scientific understanding of the universe. Computer-based modeling could be one of the approaches that are aligned with the above arguments in terms of using the language and tools of the science in socially situated activities (Palincsar, Anderson, & David, 1993).

The following premises highlight the advantages of using computer-based modeling for science learning purposes. First, creating models involves a cognitive process of representing and processing information that leads to understanding and constructing knowledge (Toth, Suthers, & Lesgold, 2001). Modeling, therefore, becomes a tool for the construction of one's developing knowledge (Larkin & Simon, 1987). Second, modeling can function as a tool to mediate dialogue between peers (Roth & McGinn, 1998). Third, it provides an opportunity for coordinating "doing" and "thinking" as a metacognitive activity, which is a central component of a methodology in teaching science inquiry (Novak & Gowin, 1984). Finally, modeling focuses (and constrains) student thinking of scientific phenomena in terms of a system with objects, variables, and relationships (Peppert, 1991; Toth et al., 2001; Zhang, 1997), and thus becomes a way of thinking about science phenomena.

Interestingly, but unfortunately, there are varied meanings of the terms "model" and "modeling" in both daily and academic life (Gilbert & Osborne, 1980; Greca & Moreira, 2000; Harrison & Treagust, 2000). As Gilbert and Osborne (1980) pointed out, misuse and misunderstandings of models (as well as their embedded meanings) in science teaching could lead to later academic failure. Therefore, there is a need to define these terms so that readers understand what is meant by "models" and "modeling." Below I describe the key ideas.

What Is A Model?

A model is a simplified representation of a system that concentrates attention on specific aspects of a system, such as more complicated ideas, objects, events, or processes. (Gilbert, Boulter, & Rutherford, 1998; Ingham & Gilbert, 1991). For example, Dalton's atomic theory provides a method to think about the nature of atoms that is based on scientific data with inferences and hypotheses. The specific aspect of a system in a model can be either complex, or different in scale to that which is normally perceived (Gilbert & Osborne, 1980). Models, thus, could represent, explain, and predict natural phenomena. For example, computer-based modeling, as a way to representing ideas, helped discover the structure of DNA (Latour, 1987).

This dissertation focuses on "external models" (Buckley, 2000; Gobert, 2000; Schwarz, 1998; Spitulnik et al. 1998; Stewart, Hafner, Johnson, & Finkel, 1992; Stratford, 1996; White & Frederiksen, 1998) that people can see and share. Based on the media in which models are materialized, there can be two types of external models: Physical models and computer-based models. Physical models are models that can be seen as concrete objects such as a three-dimension model building or a drawing on a paper. Once they are constructed, they are physically materialized and hard to change. Physical models might be different from the originals in terms of the material, size, color, and function, as well as purposes, but they have some features that match what they represent. Studies have shown that children as early as first graders are able to design, build, test, and evaluate physical models (Penner, Giles, Lehrer, & Schauble, 1997).

Computer-based model are constructed on a computer using model construction programs. The advantage of computer-based models is that they can easily be modified and duplicated. Since computer-based models are inherently dynamic, it is also easy to run simulations and test their functions (Stratford, 1997). Programs that can be used to create and/or manipulate computer-based models for middle and high school students are introduced in the following section.

A number of researchers talk about "mental models" (e.g. Greca & Moreira, 2000; Johnson-Laird, 1983). For them, mental models are representations with dynamic structures that are created on the spot to meet the demands of specific problem-solving situations. They emerge out of the "beliefs" and "presuppositions" held by a learner (Vosniadou & Brewer, 1994). There is an implicit assumption when researchers talk about "mental models". Certain external media can represent human beings' mental models and people can infer a person's mental model by his/her external model. However, mental models are not the focus of this paper; rather, I focus on models in the materialized format, especially computer models that students can plan, build, test, and share with their peers and teachers as tools to construct their understanding of science content.

What Is Modeling?

There are some varied definitions of the term "modeling" as well. Gobert (2000) calls the model creating process "model formation"; others simply call it "model building" (Buckley, 2000; Harrison & Treagust 2000). In a broader sense, "modeling" involves a model formation process, which includes data collection and analysis as well as primary planning and model building. In this dissertation, modeling happened in this broad sense because students conducted investigations before they created computer-based models. However, the process of data collection and analysis was not the focus of this study.

Two types of computer-based modeling programs have been used in K-12 schools. The first type of modeling programs are domain general because they can be used to create models of different domains including science and other fields (Penner, 2000). For example, the computer-based modeling programs STELLA and Model-It have been used to build models in water ecology, decomposition, biology, history, and other subject areas (Mandinach, 1989; Stratford, 1996). Although they can be considered "domain general" programs, the models created by the programs are still of certain domain(s). However, they have common characteristics that are important for understanding scientific phenomena. The models created by STELLA and Model-it promote system thinking by considering the phenomena being modeled as a system with interactive relationships (Mandinach, 1989; Metcalf, Krajcik, & Soloway, 2000). Another example is a computer-based modeling program called StarLogo, which has been used to model decentralized systems with collective agents (Resnick, 1996).

The second type of modeling programs are domain-specific because they can only be used to create models and/or run simulations (Stratford, 1997) that represent specific domain knowledge and legitimized rules in the subject areas. The ThinkerTools program and Genetics Tool Kit program are two examples of this type of modeling program. The ThinkerTools program is a modeling program for teaching physics. It uses a simulation based modeling program that embodies the principles underlying Newtonian mechanics. It is used with a curriculum of inquiry, discovery, and theory-generation. Students observe real-world motion phenomena, use ThinkerTools to explore the phenomena in more detail (and with greater consistency and repeatability), formalize a theory (i.e., a model), and then return to the simulation to verify how well their theory predicted behavior. It helps integrate the learning of subject matter with learning about the nature of scientific knowledge (Schwarz, 1998; White, 1993; White & Frederiksen, 1998).

Genetics Tool Kit is a program that teaches high school biology. It allows students to explore fruit fly breeding and Mendelian genetics in a virtual lab. Students pose problems and solve problems by conducting inquiry using the tool and communicating their ideas with their peers. By using the tool, students are able to engage in activities like those of practicing scientists (Cartier, 2000; Stewart et al., 1992).

In summary, there are some computer-based modeling programs that allow students to construct, modify, run simulations, and facilitate communication between students. These programs make computer-based modeling accessible to students. However, more research is necessary about how they support student learning during the modeling and/or simulation processes. Studying about student modeling processes and modeling practices provides a way to understand how modeling programs help student learning.

What Are Modeling Practices?

Lave and Wenger (1991) use the term "practice" to characterize actions that are situated in a socio-cultural context. A practice involves skills, resources, and tools, and is mediated by personal and cultural purposes. Students as learners could learn in a meaningful way through “fields of practice”, such as science, when their tasks are complex enough to be “authentic” (Barab & Duffy, 2000). Computer-based modeling is authentic because it involves the skills, resources, and tools with the purpose of performing and understanding science.

Modeling practices are scientific practices that are involved in modeling. When doing science, scientists try to develop explanations about what causes a particular phenomenon in nature. The goal of scientists is to develop an understanding of how various parts of the natural world work. To do this, scientists design experiments, make observations, analyze data, and identify patterns in data, then develop and test explanations for those patterns. The explanations are called scientific models. Scientists need to use drawings, graphs, equations, three dimensional structures, or words to express their ideas so that they can share and communicate with colleagues. Scientists need to evaluate their models in terms of whether they can explain all the data of the phenomenon, whether using a model can predict the behavior of the modeled system, and whether the model is consistent with the ideas of their colleagues so that their model can be accepted in order to contribute to the field. Usually, there are multiple models that can explain the same phenomenon in one way or another. Among them, there might be a best model and sometimes it is impossible for one model to explain all the behaviors of a system. Models in reality are experiencing constant revision in order to explain new phenomena. Models maybe revised or even abandoned when they are not able to explain new phenomena, or more data maybe needed to create or revise old models or create new ones (Carey & Smith, 1993; Dunbar, 2000; Grosslight et al., 1991; Latour, 1987; Latour & Woolgar, 1979; Lemke, 1990).

In the literature, the following modeling practices have been identified when scientists or science students plan and create models. Planning refers to the activities and processes during which modelers decide what to model and what should be included in models, such as asking a driving question about what to model on, deciding on objects/variables, and considering what relationships are more important (Stratford, Krajcik, & Soloway, 1998). Usually the practice develops before the real modeling actions in creating, testing, or modifying a model. Analyzing refers to activities and processes in which modelers decompose a system under study into parts for scrutiny (Stratford, Krajcik, & Soloway, 1998). For example, for a water quality model, students might decompose a water ecological system into objects such as streams, plants, water animals, people, factories, and so on and then assign variables to each of the objects in order to study the interrelationships of variables in the system. Constructing refers to the activities and processes of creating models that externalize modelers' ideas in materialized formats (Gilbert, Boulter, & Elmer, 2000; Gobert, Snyder, & Houghton, 2002; Wu, 2002). For example, modelers can use paper and pencil, computers, or other materials to create models for a variety of purposes. Interpreting involves activities and processes in which modelers generate meanings from what they build and reconstruct the phenomenon or concepts represented by a model (Gilbert, Boulter, and Elmer, 2000; Gordin & Pea, 1995; Latour, 1987). Reasoning involves logical thinking about and with models (Roth & McGinn, 1998) such as generating hypotheses, making predictions, constructing evidence, justifying arguments, and making conclusions. Synthesizing refers to activities and processes that ensure the different parts of a model fit together so that they represent the complete phenomenon (Stratford et al., 1998). For example, when creating a model of "What affects water quality?" students should include the major variables that affect water quality, such as temperature, dissolved oxygen, conductivity, turbidity, and pH. Critiquing and evaluating (Gobert, Snyder, & Houghton, 2002; Latour, 1987; Schank, 1994) involves the activities and processes of deciding the quality of models according to certain concepts, instruments, beliefs, and value systems. Usually, anomalies are discovered during evaluating and critiquing (Dunbar, 2000). Publicizing and presenting (Latour, 1987) involves actions and processes to make models available to other scientists in the community. This is an important way for scientists to present findings to convince their colleagues about what they have found based on their investigations. It is also an important way for the models to be critiqued, evaluated, and shared by members of the scientific community. Some of these modeling practices and their sub-categories are examined closely in this dissertation.

Findings from Previous Studies

Modeling Practices

The characterization and description of the nature of student modeling practices is the major focus of this study. Below, I review the literature on student modeling practices, especially computer-based modeling practices.

According to science education researchers, modeling practice is the central part of scientists' daily lives. A model is one type of inscription. It is an external representation of a phenomenon or system that scientists need to describe, explain, and/or predict the behavior of that phenomenon or system (Gordin & Pea, 1995; Latour, 1987; Roth & McGinn, 1998; Woolgar, 1988). Therefore, modeling practice is representational practice or inscriptional practice. Based on the literature, I am able to characterize some of the representational practices, such as constructing, comprehending, comparing, and critiquing (Roth & McGinn, 1998), and model publicizing, critiquing, and revision (Latour, 1987). These practices provide a base from which to connect the school science I studied and real science. However, the descriptions of the practices in science were either too messy or without detailed definitions.

Few studies tried to describe or promote student modeling practices. Schwarz (1998), from her empirical studies, concluded that a model-oriented science classroom better emulated the purposes and practices of the scientific community. In a high school biology course, Passmore & Stewart (2002) tried to teach the practices of evolutionary biology by allowing students to develop, elaborate, and use one of the discipline's most important explanatory models - Darwin's model of natural selection. During a 1-week summer camp, Barab and his colleagues (2001) studied the modeling practices of high school students who worked in activity groups with 3-dimensional modeling software to develop virtual worlds of solar system. A network methodology was used to trace student modeling practices. The findings of this study suggest that becoming knowledgeably skillful with a particular practice or concept takes time and should go through iterative cycles. It concludes that student understanding of certain practices or concepts depends on contextual demands and available resources. In summary, the studies show that with support, students are able to exercise and understand their modeling practices that are embedded in "authentic" contexts.

For past studies of Model-It, Jackson and her colleagues used a learner-centered design approach with built-in scaffolding made computer-based modeling accessible to high school students (Jackson et al. 1994; Jackson et al. 1996). Stratford and his colleagues (1998) found that the use of Model-It engaged students in a range of cognitive strategies in computer-based modeling, such as analyzing, relational reasoning, synthesizing, and testing and debugging. One of the few but comprehensive evaluation of models created by Model-It was done by Singer and his colleagues (Singer, Krajcik, & Marx, 2000). Sample final models of urban middle school students (n=41) were randomly selected out of 240 students from four schools. Quantitative analysis includes a descriptive analysis that included the number of a) total factors, b) valid factors, c) total relationships, and d) valid relationships. Using qualitative analysis they identified some common errors that made a factor or relationship "not valid". Errors of variables include inappropriate object association, duplication that having multiple factors represented identical traits; and irrelevant variables that is not related to the purpose of the model. Commonly identified "relationship" errors include directional error in which relationship illustrated a cause and effect relationship that was reversed, direction of effect error in which relationship illustrated an increasing effect when the appropriate relationship is decreasing and vice verse and illogical connection in which the factors paired in the relationship are not related. Collectively, the study found that over half of the sampled models (54%) contained errors with associating factors with appropriate objects and over forty percent of student models sampled contained at least one relationship that was unrelated to the central theme of the model. Wu (2002), in her study that used Model-It as part of student inscriptional practices, characterized middle school student inscriptional practices as construction, interpreting, reasoning, presenting, and critiquing. Since modeling practices were only part of the study, Wu did not provide a sufficiently detailed account of student modeling practices. In the recent studies with Model-It, we have identified the following modeling practices: planning, searching, analyzing, synthesizing, explaining, and evaluating (Fretz et al., 2002; Zhang et al., 2001). These studies provide the conceptual framework and methodological base for my study.

Content Knowledge

Modeling can be an effective instructional tool to highlight important information such as the major concepts and structures of a system (Gobert & Buckley, 2000). Models, therefore, could reveal hidden structures or processes that are fundamental to an understanding of phenomena (Glynn, Britton, Semrud-Clikeman, & Muth, 1989). Furthermore, modeling can reveal the interdependent nature of a system (Richmond, 1991). As with concept maps, while creating models, students make meaningful connections between concepts (Novak & Gowin, 1984). However, a computer-based model is able to include much more detail than a concept map because it can have descriptions of variables or detailed definitions of relationships in addition to the labels of variables and relationships. Furthermore, students can run and revise their model with the dynamic feature of computer-based modeling tools.

Increasingly, empirical evidence has shown that using models and modeling in science provides students with opportunities to construct understanding of subject matter (Finkel & Stewart, 1994; Schwarz, 1998; Spitunik, 1998; White, 1993). White (1993) described an approach that enables sixth graders to develop conceptual models that embodied the principles underlying Newtonian mechanics, and to apply their models in making predictions, solving problems, and generating explanations. This approach integrates the learning of the subject matter with learning about the nature of science. The studies found that sixth graders taught with the experimental curriculum solved classic force and motion problems and performed better in a variety of tests including content tests than did high school students taught with traditional methods. The studies also found that low-achievers made significant gains using the computer-based modeling enhanced

ThinkerTools physics curriculum (White & Frederiksen, 2000; White, 1993; White & Frederiksen, 1998).

Studies with the Genetics Construction Kit showed that students routinely discussed key genetics terms and principles when they constructed, revised, and ran simulation with genetics models. The simulation allowed students to engage in knowledge production and significantly enhanced their experience with scientific inquiry (Finkel and Stewart , 1994; Stewart et al., 1992).

In previous studies with the use of Model-It, Stratford (1996) showed that modeling allows students to build content understanding of the phenomena they chose in a water ecology unit. Spitulnik (1998) showed that an inquiry-based modeling unit (i.e. a Global Climate Change unit) allowed students to build content understanding by identifying key ideas in a problem area and building relationships and explanations of phenomena. A study, which examines a set of models created using Model-It during a high school investigation of a local creek, demonstrated that students showed more understanding of specific content than the strategic or epistemological aspect of modeling (Talsma, 2000). It seems that using Model-It promoted student conceptual understanding of content domains.

Modeling Knowledge

Several studies that engaged students in modeling practices also showed improvement in student epistemological understanding of the nature of modeling (Cartier, 2000; Gobert & Discenna, 1997; Gobert, Snyder, & Houghton, 2002; Schwarz, 1998). Given the focus of this dissertation, student modeling knowledge and its changes that were captured by pre-and post-interviews of target students are not addressed here.

The modeling knowledge that was addressed in the dissertation was captured by the primary data source—the process videos.

Modeling as Artifact Construction

Increasing evidence has shown that models and modeling make student thinking (conceptions of the world) visible and allow students to construct artifacts, facilitate conceptual change, and develop content understanding (Jackson et al., 1996; Mellar, Boohan, Bliss, Ogborn, & Tompsett, 1994; Schwarz, 1998; Stewart et al., 1992; Stratford, 1996; White, 1993). Further, the physical nature of models also allows students to communicate, critique, and reflect on their understanding of science phenomena.

As for previous studies with the software Model-It, Spitulnik (1998) suggests that creating artifacts with Model-It helps high school students make connection between concepts and allows students to build multiple representations of their knowledge. Stratford (1996) indicates that high school students who use Model-It are able to create meaningful models of complex phenomena. The use of the software seems to help students construct, test, and refine their understanding of these systems.

Metacognition

There seem to be few studies that have investigated metacognition during student modeling. However, White and Frederiksen (1998; 2000) specifically use modeling to foster student metacognition in order to improve science learning. Their ThinkerTools study group claims that making complex science, such as physics, accessible to a wide range of students can be achieved by facilitating the development of metacognitive knowledge and skills. They further proposed three types of metacognitive knowledge that students might need. Self-knowledge refers to student awareness of what expertise they have, the forms that their expertise can take, and when and why their expertise might be useful. Self-regulatory skills include skills for planning and monitoring, such as determining goals and developing strategies for achieving those goals and then evaluating their progress to see whether their plan needs to be modified. Self-improvement expertise includes expertise in reflecting on their knowledge and its use to determine how to improve it. Students would then be able to learn about the nature and utility of scientific models as well as the processes by which they are created, tested, and revised. The inquiry cycle (i.e. an iterative process of question→predict→experiment→model→apply and then start from question again) was the strategy that the teachers and researchers used in the curriculum to foster student metacogniton. Their research results showed that the curriculum and software modeling tools made the difficult subject of physics understandable and interesting to a wide range of students. Furthermore, students were able to transfer what they learned about inquiry in the seventh grade to even some non-physics subjects later, such as social studies, mathematics, and English. Students felt that the inquiry cycle worked for research projects in those areas.

Bednar and her colleagues (Bednar et al. 1991) argue that the ability to explain and defend decisions is related to the development of metacognitive skills. In the cases White and her colleagues (White and Frederiksen, 1998; 2000) discussed, it seemed that metacognition is domain general because students were able to apply the inquiry cycle in different subject domains, including both nature science and social science to guide their investigation. On the other hand, while claiming that the ability to explain and defend decisions is related to the development of metacognitive skills, Bednar and her colleagues (1991) also implied that the practices students engage in learning is domain-specific. Therefore, the cited literature shows no consensus on how metacognition might affect student learning practices.

Social Aspect of Learning (Collaboration)

Science is a human enterprise with social practices (Latour, 1987; Roth, 1998). It is argued that model building and investigation alone will not necessarily lead to understanding; instead, these activities serve as a basis for discussions between the teacher and students on critical issues from the learning context (Penner, Lehrer,& Schauble, 1998). Due to the physical nature of models, especially computer-based models that can be duplicated easily, they can be shared among students for sense making, comments, and feedback. Model construction processes can also be socially mediated, involving collaboration and discussion among learners (Penner, 2001). An individual's conceptions in a model can be critiqued and revised when publicized. This process facilitates student conceptual change of understandings of certain phenomena. While engaging in creating models, students experience the scientific practices that are enacted by scientists. For example, students can experience planning, building, testing, evaluating, and talking with others about models of phenomena for the construction of scientific knowledge in a way that is meaningful to them (Stratford, 1997).

As for the nature of learning in a "community of learners" (e.g. Brown, 1992), some researchers characterized the process of "learning by collaborating" as a search for convergence among members (e.g. Roschelle, 1992). Some researchers, however, disagree with this claim. Using some of the same data that were mentioned in Roschelle's study (1992), Shirouzu, Miyake and Masukawa (2002) make a different conclusion. After re-analyzing the protocol data of collaborative learning processes in Roschelle (1992), they showed that members' verbalizations reflecting their interpretations or re-interpretations are individualistic through the processes. However, it seems that no matter student thinking becomes individualistic or convergent, collaborating allows students to communicate, discuss, or even debate to clarify their ideas, thus likely deepening their understanding.

Scaffolding

Given the premises of what models and modeling can do in helping students to learn science, students have a number of difficulties that limit their ability to benefit from modeling practices. For example, students usually have limited experience with creating and using models, and they lack advanced mathematical skills (Jackson et al., 1994; Quintana, 2001; Stratford et al., 1998). Scaffolding enables students to conduct modeling tasks that would otherwise be out of their reach (Fretz et al., 2002). The purpose of scaffolding is to provide support to extend student competencies according to what students have previously known (Bransford et al., 2000; Wood, Bruner, & Ross, 1976).

Some researchers have used a modeling enhanced curriculum (ThinkerTool enhanced physics curriculum) to promote physics learning. This modeling program was designed with appropriate scaffolding. Student modeling as well as simulation was supported by the teachers. Results of pre- and post tests on student content knowledge, as well as surveys and interviews on student modeling knowledge showed that computer-based modeling correlated to student improvement of content knowledge and epistemological understanding of models and modeling in seventh grade (Schwarz, 1998;

White & Frederiksen, 1998). Using observation data, such as classroom videos, a few other studies have shown that computer-based modeling tools and their offshoots were used with some degree of success in high school classes, such as STELLA (Mandinach, 1989; Schecker, 1993), Logo (Resnick, 1996), and Genetics Tool Kit (Stewart et al., 1992).

Model-It has an emphasis on tool scaffolds (Fretz et al., 2001; Jackson et al., 1994; Kolodner, 2001; Metcalf, 1999). It is understandable that although teachers play a major role in classroom teaching, their expertise in modeling varies. The more scaffolding the tool can provide, the more flexible the teachers can be. In this study, students used the modeling tool Model-It. A detailed introduction to Model-It as well as the scaffolding it contains is presented in the methods section. Study of the effectiveness of scaffolding, however, is not the focus of this dissertation.

In summary, computer-based modeling seems to have the potential to help students to experience modeling practices, and to develop content knowledge and an understanding of the nature of science. Scaffolding in software makes computer-based modeling accessible to students. However, more research is necessary to study the modeling practices that middle school students demonstrate when using a modeling tool designed for learners.

In this chapter, I have reviewed the literature that is relevant to student learning through modeling. In the next chapter, I discuss how I used the framework that has been developed in this chapter to collect and analyze data, and generate findings in order to answer the research questions.

CHAPTER III

RESEARCH METHODS

As described in Chapter one, the research methodology of this study follows the "design-based research" framework (Brown, 1992; Collins, 1992; The Design-Based Research Collective, 2003) and was also aligned with a qualitative tradition (Erickson, 1986).

In this chapter, I describe techniques from the literature that support the methods used to answer the research questions of this study. This 8-month, classroom-based study aims to characterize student modeling practices and their changes over time. To broaden the scope of our first enactment of the curricula, this study also intends to identify and characterize the major aspects of the learning environment. I have described the framework as well as the major dimensions of the design in Chapter 1 (Figure 1.1). I describe the setting in which the design was implemented in the following section. As indicated above, this second cycle of the enactment of the design has similar phases as the initial enactment. The outcomes are reported in Chapter four. Lessons learned are addressed in the "Discussions and Implications" section in Chapter five.

Context

School and Science Program

The school where I conducted this study had an existing relationship between its teachers and university researchers. It is an independent school in a Midwest university city, serving a sixth to twelfth grade population with a student enrollment of approximately seventy-five students per grade. The school generally admits students from the upper two-thirds of standardized test norms.

My study was conducted in three seventh grade science classrooms taught by two teachers. The study was part of a larger research project called KDI-ASSESS[1]. The teachers in the science program have been working with university researchers to develop and implement interdisciplinary and integrated project-based science curricula for about ten years (Novak & Gleason, 2001). The goal of the science program was to promote students to develop in-depth and integrated understandings of fundamental science concepts and process skills within a context of inquiry. During each school year, several science units were explored that incorporate fundamental science concepts across several science disciplines. Each unit began with a driving question (Marx, Blumenfeld, Krajcik, & Soloway, 1997) that was used to organize class activities and provided students with a real life context. Teachers first modeled an investigation process. Students then collaboratively worked with their group members to conduct various investigations to find answers to their own driving questions related to their class driving questions. Teachers provided substantial support as students engaged in inquiry through activities such as asking questions, collecting data, analyzing data, presenting ideas, and generating conclusions (Krajcik et al., 1998). This instructional approach is consistent with the National Science Education Standards (NRC, 1996).

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[1] "Analyzing Scaffolding Software in Educational Settings in Science" (Project ASSESS) is a 3-year, National Science Foundation (NSF) funded research project, that falls under the categories of "Knowledge Distributed Intelligence" (KDI). URL:.http://www.letus.org/kdi

Curricula and time line

During the school year of 2000-2001, two science units, the water quality unit and the decomposition unit, were explored in the three seventh grade classes. In the benchmark lessons, teachers introduced the basic concepts of water quality (See Appendix A for the major concepts introduced) and decomposition (See Appendix B for the major concepts introduced) and also provided guidelines for students to search for information to guide their investigations. (See Appendix C an example).

Both units were introduced based on the same instructional approach. Students were engaged in a similar inquiry process that involved asking questions, collecting data, analyzing data, presenting ideas, generating conclusions, and writing reports (Novak & Gleason, 2001). Students experienced three rounds of data collection for the water quality unit in order to investigate the change of water quality over a year. In this study the water quality unit is labeled as water quality I (WQ I) in the fall season, water quality II (WQ II) in the winter season, and water quality III (WQ III) in the spring season. The time spanned from September 2000 to June 2001 (Students did not do computer-based modeling at the end of WQIII). Between these three water quality sub-units, students investigated decomposition and its related concepts. The time span for the decomposition unit was from January 2001 to April 2001. Table 3.1 shows when and for how many days students were engaged in computer-based modeling after their investigations and other inquiry activities. The intensive observations and data collection were made on those days at the end of WQI, WQII, and decomposition Units, and during the modeling class cycles. The modeling cycles when students created computer-based models were part of the teachers' curricula.

Table 3.1. Time of Computer-based Modeling Cycles

Water Quality I	Water Quality II	Decomposition
Dec. [1], 7, 8, 11, 2000; Jan. 8 {10, 11}, 2001	Mar.14, 15, 16, {19, 20, 21}, 2001	April 30 & May 1, 2, 2001

Note: 1. [ ] The day before students worked on Model-It in pairs or groups.
2. { } Student pairs or groups present their models to the whole class

The Water Quality Unit

Throughout the unit, the teachers used short lectures to present information. They used experiments, group activities, and videos to introduce students to key ideas in science. These key ideas included the fundamental concepts in the curriculum, the process of inquiry, collaboration, and the use of various technological tools.

During each of the three water quality seasons (i.e., fall, winter, and spring), students investigated the stream behind their school. Teachers first modeled the investigations and modeling processes. After teachers modeled the inquiry process, for example, providing a class "driving question" (Krajcik, et. al, 1998) of "What is the quality of water in the stream behind our school?" for investigation, students asked their own questions about water quality and worked with one or two classmates. Five major water quality tests were conducted iteratively during the three seasons, including pH, DO (Dissolved Oxygen), conductivity, turbidity, and temperature change. Besides these five water quality tests, some other major concepts--such as neutralization, buffer, thermal pollution, eutrophication, topography, and watershed--were also introduced by the teachers.

At the end of each investigation cycle, such as in the fall investigation (WQ I), students worked in pairs or groups to construct computer-based models to extend and present their understanding of water quality in terms of their driving questions. Teachers first spent about 35 minutes in class demonstrating how to use the computer-based modeling software, Model-It, and the related concepts of models and modeling, such as independent and dependent variables. Students then constructed their models based on their own driving questions. In some of the sessions, teachers asked students to critique their own and other group's models. At the end of the modeling cycles in WQI and WQII, students were asked to present their models to the whole class.

Decomposition Unit

A similar instructional approach occurred in the decomposition unit. Students searched and wrote background information about decomposition. They then investigated the decomposition of common materials in daily life. The required material items are: plastic, metal, Styrofoam, paper, wood, cloth and food. Unlike the water quality unit, in which students had to collect data about the five water quality factors in order to decide the health of the river through fall, winter and spring seasons, students were able to ask more diverse questions about decomposition for their investigation. For example, Which items decomposed the fastest? and How can worms help decomposition? After going through their inquiry cycle, at the end of the unit, students spent two days as scheduled to create their computer-based models (Table 3.1). Given the time constraints, students spent less time on computer-based modeling in the decomposition cycle than on the water quality unit.

Students and Teachers

Forty-four seventh graders participated in this study (Class I: 12 students, 8 girls; Class II: 15 students, 8 girls; Class III: 17 students, 10 girls). Among the participants, three were Asian-American, one Russian, one Arab-American, and another one was Hispanic. The rest of them were Caucasian.

In each class, two pairs or groups of target students were nominated by the teachers. Those students and their parents consented to their participation for intensive observation. These target students were chosen by considering their gender, academic achievement level, and ability to verbalize their learning process. In the water quality unit, all of the target students were Caucasians, although one of them had Asian Indian heritage. Because of a parent complaint regarding lack of interaction with other students, in the decomposition unit, target students were either swapped or totally changed, especially for Class III. Classes II and III each had a three-student group as target students. Among the target students, there was one Arab-American, the rest were identified as Caucasian. Table 3.2 and 3.3 summarizes the information of the classes and target students. These student pairs worked together in their investigations before they created their models together in the two units.

Class I was taught by Alice[2] who had taught for ten years, and had a BS degree with a major in broad field science and a minor in biology and health, and a MA degree in adolescent development. Carol taught Class II and III and had 28 years of teaching experience. She had a BS with a major in biology and a minor in chemistry, and a MA in special education. Both teachers had secondary science teaching credentials. The teachers met regularly before the first class period for planning curriculum, creating materials, sharing handouts and discussing student progress.

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[2] Pseudonyms for teachers and students that maintain their gender are used throughout this paper.

Table 3.2. Target Students—Water Quality Unit

Class	Student pair	Gender	Academic achievement (According to the teachers)
Class I taught by teacher Alice	Shirley	F	Medium
	Cathy	F	High
	Charles	M	Medium
	Simon	M	High
Class II taught by teacher Carol	Jackie	F	High
	Elias	M	Low
	Shaw	M	Medium
	Lisa	F	Medium
Class III taught by teacher Carol	Nathan	M	High
	Kelly	F	High
	Don	M	High
	Abby	F	High

Table 3.3. Target Students—Decomposition Unit

Class	Student pair	Gender	Academic achievement (According to the teachers)
Class I taught by teacher Alice	Simon	M	High
	Cathy	F	High
	Charles	M	Medium
	Alisa	F	High
Class II taught by teacher Carol	Jackie	F	High
	Sasha	M	Low
	Elias	M	Low
	Shaw	M	Medium
	Zech	M	Medium
Class III taught by teacher Carol	Nathan	M	High
	Mike	M	Medium
	Elena	F	High
	Ahmad	M	Medium/High
	Abby	F	High

Researcher Involvement

By the time of the data collection for this study, our research group had completed an initial enactment of the curricula and study during school year 1999-2000 (Fretz et. al., 2002; Zhang et al, 2001). Therefore, through previous classroom observation, meetings with teachers and researchers, and readings, I was familiar with the school routine and the philosophy and styles of the teachers. A norm of being observers and researchers in the classes had also been established. The other two researchers who also collected data in the classes and I were introduced to the students. We briefly introduced our research project and answered student questions. There was good rapport among the teachers, students and researchers.

In classes, I was a researcher conducting the study and did not participate in classroom activities, although I sometimes answered student questions about the tasks they were supposed to do. When students used the modeling program, I was a helper and interacted with them for content questions and tool problems.

Computer-based Modeling Tool: Model-It

The modeling tool used in this study was called Model-It. 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.

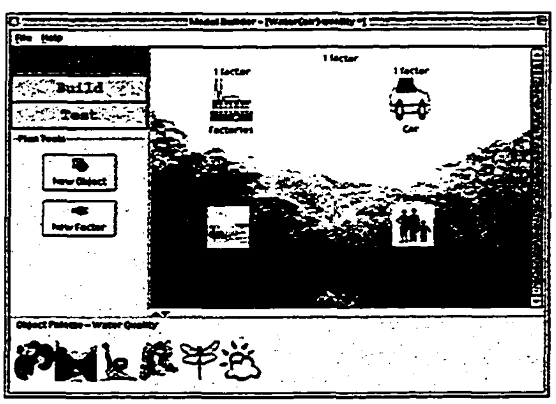

Figure 3.1. Plan Mode

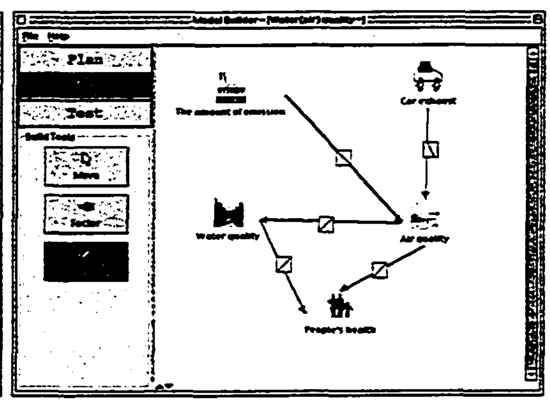

Figure 3.2. Build Mode

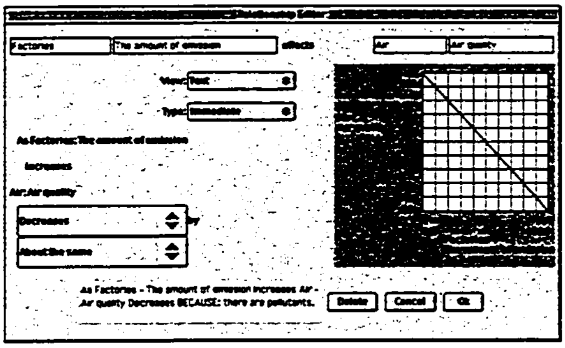

Figure 3.3. Relationship Editor

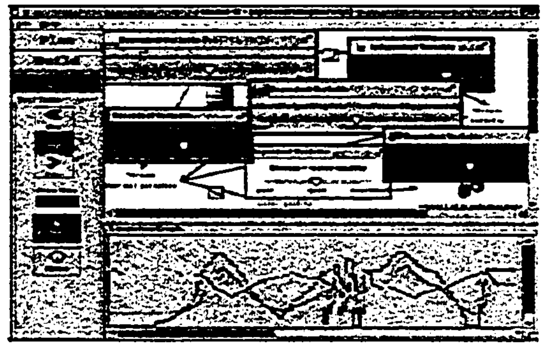

Figure 3.4. Test Mode

Model-It has three modes (Plan, Build, and Test) that sequence the model building process. In plan mode (Figure 3.1), a user (or users) creates, defines, and describes objects and specifies qualitative or quantitative variables[3] associated with specific objects. An object is an entity in the natural world that can be seen or detected, such as a stream, plants, or people. A variable is a measurable trait of an object. It can be measured either by number or qualitatively by textual values. For example, stream temperature can be measured by numbers. It can also be defined qualitatively, such as high, medium or low.

In the build mode (Figure 3.2 and Figure 3.3), the student builds causal or relational links between the variables that are represented by both verbal description and graphic representation. A typical relationship in a verbal (or textual) form is: (As)[4] FARM LAND-the amount of farmland (increases), STREAM-water quality (decreases) (about the same) (because) rain can wash pollutants, such as fertilizer, pesticide, into the stream. The relationship includes the direction of the relationship, that is, when a variable increases, how does the variable affect changes. The effect can be either "increases" or

---

[3]In our studies (e.g. Zhang, et. al., 2001), we used "factor" and "variable" interchangeably.

[4] Words in parentheses were set up in the program. Students could have more than one choice as being set up in the program. For example, the degree of [increase/decrease] can be "about the same", "more and more", etc.

"decreases". The relationship has its "degree of change". The change can be "a lot", "a little" and so on; The relationship also includes a "because statement" window or box. Students need to fill in the reason for the specific relationship they define in the "because statement" window. For example, if students need to give a reason for why the amount of farmland increases as water quality decreases, students could write that farmland uses fertilizers and rain can rush fertilizers into the rivers so that decreases water quality.

For data visualization, in test mode (Figure 3.4), Model-It provides meters and graphs to view and change variable values. Meters and a graph of variables versus time illustrate how the variables changed. A meter and a colorful graph line correspond to a variable. After a user clicks the "start" button to run a simulation, a meter shows the initial value of the variable. As students test their models they can change the values of independent variables and immediately see the effects on dependent variables in both meters and in the graph. If the simulation does not run the way students expect, Model-It allows them to move back to the plan or build mode to revise objects, variables, or relationships. For more information about this program, see Jackson et al. (1994), Metcalf et al. (2000), and Stratford (1996).

Data Sources

Multiple sources of data were collected during the WQI, WQII, and the decomposition unit over a period of eight months. The primary data sources for answering the first two research questions were video recordings when target students used Model-It and video recordings of whole class observations at the same time. Table 3.4 summarizes the sources of data, purposes, and group sizes.

Table 3.4. Data Sources, Purposes, and Group Size

Data sources	Purposes	Group size	Total numbers of tapes
Classroom Videos	Describe the class history of how teachers introduce modeling; teacher-student interaction in class in terms of modeling and subject matters; and student modeling practices such as planning and class presentation.	Whole class Class I (n=12) Class II (n=15) Class III (n=17)	WQ I: 21 WQ II: 16 Decomposition unit: 7
Process videos of using Model-It	Live records of target student pair computer-based modeling activities as well as practices; written and oral discourse; and model production process	2 (pairs/class) X 3 (class)= 6 pairs or groups; (WQ unit, 6 girls; Decomposition Unit, 5 girls)	WQI: 20 WQI: 16 Decomposition unit: 12

Video Recordings of Classroom Observations

The classroom videos that I used for data analysis were of those classes when teachers introduced models and modeling, when students used Model-It, and when student pair or groups presented their models to their classes in water quality and decomposition units. At the beginning of the first class, teachers demonstrated how to use the software, introduced the basic concepts of a model, such as objects, variables, and relationship, and gave instructions about student tasks and some issues that students needed to pay attention to. After the first class, introduction to the software decreased while the other instructions remain similar but shorter. Occasionally, I talked to the teachers at the end of classes about some issues raised in the class such as technology use; these conversations were captured as much as possible and were also included in the classroom videos for that class. These videos provided a broader context of where and how modeling practices occurred.

Process Video Recordings of Target Student Use of Model-It

Target student activities while using Model-It were recorded by a technique called process video (Abbreviated as PV in some places) (Krajcik, Simmons, & Lunetta, 1988). The computer monitor signal was sent to a video recorder, where the student screen activities were recorded on a videotape. Meanwhile, each student wore a microphone and the audio signal was increased with a mixer, and was also sent to the video recorder where it was saved on the audio track of the videotape. The process videotapes provided a non-intrusive way to observe student modeling actions on computer screen and their conversation simultaneously. However, the process videos could not capture student gestures or actions. In this case, classroom activity data that recorded student body language and gestures became useful as complementary data. The resolution of the videos did not allow me to read what students typed on computer screen. If there was no elaboration or follow-up conversation, I used the relevant part of student models as a supplement to determine what they wrote in the program.

Data Management and Reduction

The goal for data management and reduction was to document my data corpus and transform different types of data into texts or two-dimensional displays (e.g, tables, screen shots) for further data analysis.

Process Videos

Process videos, my major data source, captured student modeling actions, conversation, modeling practices, as well as the entire model production processes. As defined in Chapter 1, modeling actions were what students did, such as creating an object or building relationships (Table 3.5). In more detail, a modeling action, such as creating an object in Model-It, includes (In plan mode) dragging or assigning an image as either a background image or plain image, (on the popped-up object editor) typing in the object's name, filling in a description of the object in the description window, and clicking "OK" to dismiss the object editor. Such detailed descriptions of the major modeling actions are listed in Appendix D. In contrast to modeling actions, modeling practices in essence reflected student cognitive processes. For example, during a modeling process when students created objects, assigned variables to them, and then defined relationships between the variables, they actually broke the phenomenon described into smaller components of that system so that they were performing the analyzing practice. Students might not realize that they were performing this analyzing practice when they were performing the actions, but they were expected to adapt the way of thinking over time. The major categories and sub-categories of the modeling practices are listed in Table 3.6. Definitions and examples from the data sets are listed in Appendix E.

Table 3.5. Modeling Actions when using Model-It

2. Modeling actions*	2.3 Test	2.5 Irrelevant activities
2.1 Plan Mode	*2.3.1 Creating meter*	*2.5.1. Off-task*
2.1.1 Creating object	*2.3.2 Moving meter*	*2.5.2 Technical problem*
2.1.2 Deleting object	*2.3.3 Adjusting meter*	
2.1.3 Creating variable	*2.3.4 Minimizing or abandoning meters*	2.6 Possible supports
		2.6.1 Teacher/Researcher/Peer (TPR Intervene)
2.2 Build	2.4 Meta-cognitive activities	*2.6.2 Discussing tool scaffolds*
2.2.1 Modifying variable	*2.4.1 Pause and Rearranging model layouts*	
2.2.2 Deleting variable	*2.4.2 Saving*	2.7 Actions_Others (Some activities are not physically captured such as discussions with only conceptual or intellectual activities.)
2.2.3 Creating relationship		
2.2.4 Modifying relationship		
2.2.5 Deleting relationship		

Note *: 1. In some very rare cases, "*Creating variable*" happened in build mode when students clicked on "Variable button" and clicked on a variable icon so that they could create a variable with the same object with that variable. However, they could not change the object on the variable editor.
2. Code (2 6 1) is not a modeling action and is not what a target student pair or group is doing, but an outside influence that might affect their modeling actions. I put it here because it is inseparable from student modeling action.

Table 3.6. Modeling Practices when using Model-It

3.1 Planning	3.3 Synthesizing	3.5 Reflecting & Monitoring
3.1.1 Stating goals	*3.3.1 Elaborating relationship*	*3.5.1 Seeking information*
3.1.2 Discussing object	*3.3.2 Predicting*	*3.5.2 Gathering resources*
3.1.3 Discussing variable	*3.3.3 Making connections(to investigation and experiences)*	*3.5.3 Deciding the course of action (including asking reflective questions)*
3.1.4 Discussing relationships		
	3.3 Evaluating	3.6. Publicizing and communicating
3.2 Analyzing	*3.4.1 Critiquing/interpreting test results*	*3.6.1 Self-critiquing and reflecting*
3.2.1 Specifying object		3.6.2 Peer evaluating
3.2.2 Specifying variable	*3.4.2 Identifying anomalies*	3.6.3 Teacher evaluating
3.2.3 Specifying relationship	*3.4.3 Proposing solutions*	
	3.4.4 Carrying out solutions	3.7 Practices_Others

Note: 1. Definitions and examples of the modeling practices are listed in Appendix E
2. Code (3.6.2) and code (3.6.3) describe modeling practices that also involve students, teacher, or researcher out of a target student pair or group. Again, the outside participants might affect student modeling practices and their involvement cannot be ignored when interpreting student development of knowledge.

Modeling practices were inferred from student modeling actions and conversation according to my best understanding of the class context. The basic principle for me to code the modeling actions as modeling practices was that if the actions were in terms of a model component, such as an object, a variable, or relationship, but did not result in the creation of the model component, it was considered “discussing” practice, such as “discussing object”. If students created a model component, it was “specifying” practice, such as “specifying objects”. Some modeling actions, such as “saving”, did not have a counterpart in the “practice” codes, they were coded as “Practice-Others”. The same coding also applied to those practices that were not from “modeling actions”. For example, “deciding the course of action” could only be captured through student conversation so that was coded as “Actions_Others” in order to appear on the ER charts of modeling actions.

A preliminary transcription was done by three graduate researchers (including me) using the same guidelines shown in Appendix F. However, the PV transcripts were not nearly as detailed as that of my second transcripts because of limited time. Most of the audio portion of the process videos was later transcribed verbatim either by experienced transcriptionists or by me. I then added the non-verbal part of student modeling actions that could only be seen on the PVs. A detailed description of student modeling actions are explained and illustrated in Appendix D.

I also replicated student final models during the process of transcription. An intermediate model includes every model component that was built, modified, or deleted during a class period with time marks denoting when the operation of the modeling action was completed. For example, if students were creating an object and they clicked "OK" at the 21st minute and 3rd second according to the time counter on the VCR, the modeling action was marked as 2103. A replicated model also included some screenshots of the intermediate model at certain time points when I thought a screenshot was necessary right before or after some major changes happened to the model. The screenshots were captured using a technique called MyVideo (Labs, 2000), which plays a process video on a computer screen and allows screenshots to capture any frame of the video. Appendix G shows an example of the intermediate model of student pair Nathan and Kelly on the third day (Day 3) of WQI. The time mark was MMSS (M-Minute; and S-Second). For example, 0250 means an object was created (the time when the "OK" button was clicked) at the 2nd minute and 50th second of that class by reading the time counter on the VCR of the PV of that class. Using a similar format, I also replicated student final models of WQI, WQII, and decomposition. Appendix H shows an example of the final model of WQI for student Abby and Don. The two screenshots show the model layouts in plan mode and build mode. This was the model that Abby and Don created in the last 18 minutes on Day 4. Altogether, fifty-seven intermediate models and 18 final models were replicated. These models, however, were not analyzed systematically for this study. They were used only when necessary.

Altogether, fifty-seven process videotapes that were transcribed. A process video transcript captured student modeling actions, discourse (oral and written language), and description of a model in production. The transcripts allowed me to analyze the interactions among students, teachers, and material resources and products (Jordan & Henderson, 1995). On average, a tape lasted 35 minutes. Guidelines and an illustration of a transcription are shown in Appendix F. A sample PV transcript is shown in Appendix I. With time marks of the major segmentations, detailed descriptions with student pair modeling actions on computer screen and modeling practices inferred from both the oral discourse and description of student modeling actions allowed me to look at student pair learning trajectories of computer-based modeling (Barab, Hay, & Yamagata-Lynch, 2001).

In order to make it easier to code data from the process videos and further analyze data analysis, I divided the process video transcripts into different units of analysis or chunks of texts. As Wells (2000) has noted, the segmentation of spoken text into analytic units is "notoriously problematic". Further, there seems to be no consistent use of the most commonly used term, such as "episode" and "event", when dividing transcripts derived from video recordings (Barab et al., 2001; Jordan & Henderson, 1995; Spitulnik, 1998; Stratford et al., 1998; Wells, 1998; Wu, 2002). It is understandable that researchers define the units of analysis differently given their foci and granularity. Further, given the short history of using video recording in the field of education (Brown, 1992), researchers have not come to a consensus in practice on how to interpret and segment their transcriptions even though they might use similar definitions. As Jordan and Henderson (1995) state, "As analysts, we are interested in the ways in which participants make that structure visible to themselves and to each other, how they 'announce' in some sense that fact that they have reached a segment boundary in the work" (p. 59). Here the "structure" means that there was some pattern in the consecutive course of actions that can even be recognized by the participants. Therefore, my strategy for segmentation for the analysis was to try to find some consistent structure that could be recognized and shared even by the participants when they shifted from one segment to another, which had a different character (Jordan & Henderson, 1995).

In the study, since there was a basic structure designed in the software, student modeling processes were first decomposed by the natural boundaries (i.e. the Plan, Build, and test mode) (Zhang et al., 2001). Within each mode, I identified "Event". "Events are stretches of interaction that cohere in some manner that is meaningful to the participants" (Jordan & Henderson, 1995, p. 57). An event includes a bounded set of modeling activities about a common modeling action (e.g. creating objects and creating variables) (Stratford et al., 1998). If a student pair created two objects, then they moved to create variables, they started a new event. An event had a starting time mark so that the duration of each event could be calculated. In addition, there were times when students encountered technical problems, or students were off-task, or the teacher intervened; these were considered as independent events.

Second, within an event, I divided the descriptions into smaller chunks that had the same topic or focus. For example, if student pairs talked about a certain object, variable, relationship, or testing a model, the chunk of description of "discussing object, determining variable, defining a relationship, or testing" was counted as one "episode." In the above event when students were discussing two objects, the discussion of each of the objects became an episode. One episode was similar to an "ethnographic chunk" as an "easily identifiable behavioral unit" (Jordan & Henderson, 1995, p. 57).

For each pair of target students in a class session, I had the following units of analysis for their process videotape—Mode, Event, and Episode. These various units of analysis helped me zoom in and out of the process videos of a student pair in a class period (Roth, 2001). Figure 3.5 demonstrates how I identified mode, events, and episodes for student pair Simon (SP) & Charles (CF) in WQ II, Day 2. The original PV transcript excerpt follows the figure.

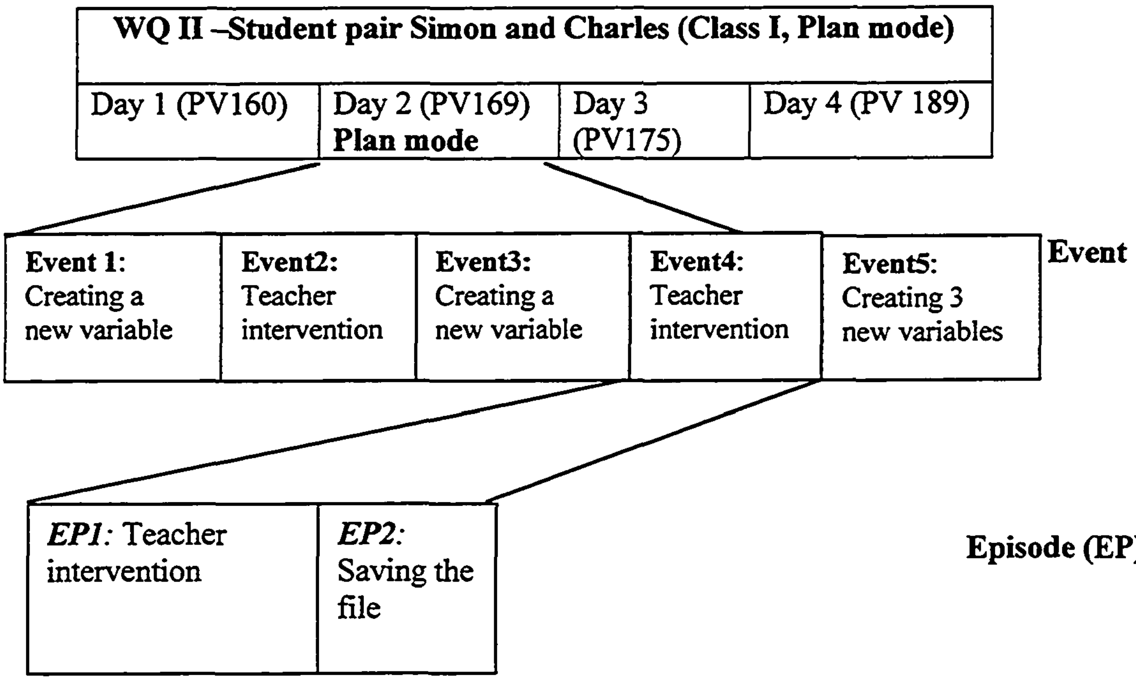

Figure 3.5. Illustration of Mode, Events, and Apisodes that Are Marked in ({ })

-------PLAN {Mode 1}
{Event 1}
0113 Charles: now we keep adding variables. {EP 1}
New variable: people.
Decide the name of variable.
Charles: people.
Simon: Wait, we need amount of people.
Charles: amount of people then.
Change high/medium/low to a lot/a group/a few.
Charles: the more people, the more other stuff.
Simon: the more people, the more...what do you mean by other stuff?
Charles: we are gonna put that in our relationship, aren't we?
Simon: but we have to describe them.
Charles: people, evil creatures that pollute.
Simon: the more people, the more pollution...
Simon types in the description.
Charles: why don't hit the button.
Simon: if you think that's OK.

{Event 2}
0257 Teacher comes: if you talk aloud about your thinking, {EP 1}
that would be very helpful.
Students say OK.

{Event 3}
0313 Charles: next variable. {EP 1}
Students search the objects they have.
Charles: let's do plants and animals.

New variable: plants/animals [object].
Charles: why did we do plants and animals?
What's our question?
Simon: what are the effects and causes of thermal pollution?
Charles: why do plants and animals matter?
Simon: plants you mean?
Charles: plants and animals.
Simon: plants and animals? That's the effect.
Charles: okay. Okay....
Name of the variable: amount of plants and animals.
Charles: description.
If there is so much thermal pollution, there will be less or no plants and animals.
Simon fills in description.

{Event 4}
0400 Teacher to the whole class: don't wait till the end before you test. {EP 1}
So make your objects and variables, build some relationships and test.

0454 Simon: we need to save. {EP 2}
Students save the file name as CFSPWinter2.
Save the file.

Classroom Videos

There were three types of classroom videos: teachers' introduction of modeling and Model-It, classes when students used Model-It, and classes when students presented their models to the whole class and received their teacher and peers' comments and feedback. The classroom videos of teacher instruction were transcribed verbatim by an experienced transcriber. Please see Appendix J for an example a transcript of teacher instruction in the first class of a modeling cycle. The transcripts allowed me to look at how teachers demonstrated the modeling actions and practices that students were supposed to exercise.

Student pair class presentations were also transcribed verbatim because they demonstrated how students communicated their ideas with their teachers and classmates, and how teachers and peers provided comments and feedback. Appendix K is an example of a student pair class presentation transcript. Student presentations at the end of WQI, WQII, and the decomposition unit allowed me to look at the changes in student understanding of phenomena that they modeled. They also allowed me to determine wether teachers' or peers' comments and feedback were included in their next round of modeling.

The classroom videos (CVs) of modeling periods were not analyzed systematically. Some of the major class events, mostly the teachers' interventions, were also captured by the process videos (PVs) because a teacher's instruction was supposed to be heard by every student in a class. Because student modeling processes were usually influenced by whole class instruction, the classroom videos illustrated the class history and could help interpret certain student modeling practices (Lave & Wenger, 1991; Roth, 2001). Therefore, they were used when needed to triangulate certain assertions.

Data Analysis

Table 3.7 lists the research questions, the major data sources, and brief overviews of the data analysis process. Figure 3.6 shows the iterative process of the data analysis (Erickson, 1986). Secondary data sources were also used to confirm or disconfirm my findings in the course of data analysis and writing.

Table 3.7. Data Sources and Data Analysis in Answering Research Questions

Research questions	Data sources	Data analysis
Q1. What modeling practices do middle school science students demonstrate during their initial computer-based modeling?	PVs of modeling periods; CVs; Models	Identifying codes (Table 3.5 & 3.6); Transcribing of PVs and CVs (see Appendix J & K for examples); Coding in NUD*IST; Creating EventRecorder (ER) charts; Using NUD*IST Reports (Outputs) and the ER charts to write class summaries of each pair of each class period; Writing session summaries for each pair of students; Generating narratives as results.
Q2. How do middle school science student modeling practices change over time?	PVs of modeling periods; CVs; Models	Same as Q1, but did it iteratively for WQ II and the Decomposition Unit and constant comparison was made to insure validity; Narratives of changes in modeling practices were made.
Q3. How does the design of the classroom environment facilitate student modeling practices?	PVs; CVs; and student notebooks and booklets	Narratives were generated through analysis and narrations of the PVs, CVs as well as checking student notebooks and booklets.

Note: 1. PV= Process video; CV= Classroom video

2. See Figure 3.6 for a detailed illustration of the processes.

Step 1: **Developing coding scheme:**
(1) Identify modeling actions (Table 3.5);
(2) Identify types and sub-types of modeling practices (Table 3.6)

Step 2: **Analysis of WQI in answering research question one:**
(1) Use the coding scheme (Table 3.5 & 3.6) to conduct coding of transcripts of the PV and CV transcripts using NUD*IST for WQI.*
(2) Create NUD*IST reports (outputs) of modeling actions and modeling practices, for each of the six pairs (See Appendix L for an example).
(3) Create ER charts of each class period of student pair modeling actions and modeling practices versus time, respectively (Figure 3.7 & 3.8).
(4) Use both NUD*IST reports of PVs and ER charts to write class summaries for each student pair of their modeling actions and practices (Appendix N).
(5) Generate session summaries for each pair of target students of WQI (Appendix O)
(6) Generate temporary assertions for answering the research question one.

Step 3: **Repeat analysis in step 2 in answering research question two:**
(1) Repeat the same operations with the same types of data for WQII and the Decomposition Unit.
(2) Compare class and session summaries to look at changes in student modeling practices listed in Table 3.8 across the six target pairs.
(3) Generate temporary assertions for answering research question two.

Step 4: **Synthesizing analyses in step 2&3 in answering research question three:**
(1) Use NUD*IST reports of CVs to write summaries of how teachers modeled modeling practices (Appendix P).
(2) Generate NUD*IST reports of code "TPR", "peer evaluating", "teacher evaluating", and "discussing scaffolds".
(3) Use the PV summaries, CV summaries, and specific code reports to write summaries of the impact of teachers, modeling software, and curricula.
(4) Generate temporary assertions for answering research question two.

Step 5: **Report assertions and share findings:**
(1) Report findings with particular descriptions as evidence
(2) Share findings with teachers** and peer researchers ***
(3) Review the narrative and test the validity of temporary assertions *
(4) Revise general assertions based on comments and feedback.

Figure 3.5. Data Analysis Procedures

Note: * A senior researcher and advisor supervised the dissertation writing process;
** Classroom teachers from whose classes I collected the data;
*** There were three graduate student researchers in the research group that shared the responsibilities of data collection, data analysis, writing, etc. I refer to them as "peer researchers".

Development A Coding Scheme

My research questions involved the historical development of student modeling practices. I also searched across different data types in order to answer these questions. To illustrate the student learning processes, I first developed a scheme for coding the transcripts. The codes were used similarly to the idea of "tracers" (Barab, Hay, & Yamagata-Lynch, 2001; Newman, Griffin, & Cole, 1989)(Table 3.5 & 3.6). The codes were specific modeling actions or modeling practices that could be observed and followed over time from the process videos, classroom videos, and other data sets that tie to the research questions.

I decided on codes for modeling actions (Table 3.5) in each of the three modes according to the ways that students were supposed to behave following the design of the program. Students had to execute certain modeling actions in order to create, test, or modify a model (Appendix D). A modeling action might also include some sub-actions. For example, the simplest modeling action--deleting a variable--included the following sub-actions: (in build mode) Clicking the "Variable" button (1); popping up the variable editor (2); clicking on the "delete variable" button on the variable editor (3).

Because metacognition was a very important aspect of student learning, I also added codes for actions that might help capture student metacognition and its changes over time (Bednar, Cunnighham, Duffy, & Perry, 1991; Flavell, 1976; White & Fredricksen, 2000). Some codes for modeling actions (Table 3.5) or modeling practices (Table 3.6) were not those of the target student pairs or groups, but of their peers, teachers or researchers' involvement in their modeling processes. Since they were important aspects of student learning during the modeling processes, they were also captured and coded.

I determined the codes for modeling practices based on previous studies and my theoretical framework. Codes such as the sub-categories of modeling practices also emerged from reviewing the empirical data corpus from the pilot study and my examination of the dissertation data corpus. First, from literature that included our first enactment, I identified the major categories of modeling practices (Dunbar, 2000; Fretz, et al., 2002; Latour, 1987; Schank, 1994; Stratford, 1996; Wu, 2002; Zhang, et al., 2001). Second, from my data management process, I identified some sub-categories of modeling practices from the data corpus, such as stating goals and deciding the course of action. Table 3.8 summarizes the definitions of the major categories of the modeling practices and examples from the data corpus. Appendix E lists the definitions and examples of the complete sub-categories of each modeling practices. Using the same codes allowed me to follow student modeling practices through the water quality and decomposition units and across different data sets (i.e. classroom observation data, such as process videos and classroom videos). The codes also allowed me to look at changes in modeling actions and modeling practices in order to answer the research questions.

Table 3.8. Modeling Practices, Definitions, and Examples

Modeling Practice	Definition	Examples
Planning (Planning)	Practices of decision-making regarding the driving question or scenario to be modeled, objects, variables, and relationships in a model (usually) before actually building a model (at brainstorming stage).	"I want to model how animals and humans affect water quality"; "We should have the amount of garbage in our model."
Analyzing	Statements and actions that decompose a large system or a phenomenon that they are going to model into sub-systems or components. The purpose is selecting the appropriate objects, variables and relationships to reflect the most important characteristics of the phenomenon in terms of the focus of the model. It may also involve student meta-cognition or reflective behavior so that they can decide what they should do next.	"What are the other variables you can think of in terms of thermal pollution?" "Do you think we should change the default initial value options?"
Synthesizing	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 or using their investigation experience for explanations and making arguments.	"It should do…when we run it." "We did not see much change of turbidity in our investigation, did we?"
Evaluating	Statements and actions when students talk about the quality of their model, present their model to others to get feedback or test the model in order to improve their model.	"Why acid rain did not change water quality?" "Yes, I think the model is complete in terms of our driving question."
Reflecting and monitoring	Modeling actions and statements that demonstrate student self-awareness of the control of modeling processes, their need for help and resources and so on. The practices show student metacognition. Therefore, the results were reported with "metacognition".	"We need to ask the teacher one more time." "Let's check our notebook for information."
Publicizing and sharing	Presenting models to the class or putting them on their web sites for comment and feedback from teachers, peers, or more knowledgeable others.	"Our driving question is how do humans affect DO. We have…as the causes and …as the effects of thermal pollution."

Data Analysis for Research Question One

For each PV transcript, a brief summary was created after I finished transcribing while my memory was still fresh. A summary included the general impression of the following aspects: Modeling actions, modeling practices, metacognition, modeling knowledge, and collaboration.

According to the first enactment of the curricula and preliminary analysis of the data corpus, I was able to develop a list of predicted findings as temporary assertions. During the transcription process, I tried to find confirming or disconfirming evidence so that I could modify or remove an assertion or add new temporary assertions.

I then coded the transcripts that were obtained from the data management process. In order to answer research question one, "What modeling practices do middle school science students demonstrate during their initial computer-based modeling?", I used the codes for modeling actions (Table 3.5) and modeling practices (Table 3.6). To help facilitate coding and manipulate the transcript files, a software program, NUD*IST® (Richards, 1999), was used. NUD*IST is a qualitative data analysis tool. It allowed me to import the transcripts of "Text only with line breaks" format and code the transcripts according to the codes that I set up in the program. This tool, then, allowed me to search by one code or multiple codes and to make reports that on the instances of certain code(s). Appendix L shows an exemplar NUD*IST report of instances of some modeling practices in process video transcripts.

NUD*IST Coding and Analysis of Process Video Transcripts

In addition to using modeling actions and modeling practices as the major codes listed in Table 3.7, I also had administration codes (Table 3.9) in order to manage the transcripts that were from different classes, different curriculum units, and for different pairs of target students in NUD*IST. In Table 3.9, each student had a pseudonym and also had an abbreviated name in a parenthesis. The abbreviated name, such as ST, was used during the transcription for convenience because the same name could even appear for hundreds of times during one class period.

Because some student pairs were swapped or changed in a later decomposition unit, I assigned an administrative code for each target student instead for a target pair. This consideration simplified coding and analysis in NUD*IST because I could easily pull out records for an individual student if necessary. Because the target students were still in the same class and were taught by the same teachers, I made my assertions by looking at all the pair data collectively. For example, what did the analyzing practice look like for students in WQI and how did it change over time. I looked across the six pairs to make the narratives and assertions. Therefore, overall, the target students were still representative of the classes.

Table 3.9. Administration Codes for Coding Process Video Transcripts in NUD*IST

1. Administration	*1.2.4 Simon*	*1.2.13 Alisa*
1.1 Class	*1.2.5 Jackie*	*1.2.14 Sasha*
1.1.1 Class I	*1.2.6 Elias*	*1.2.15 Mike*
1.1.2 Class II	*1.2.7 Shaw*	*1.2.16 Elena*
1.1.3 Class III	*1.2.8 Lisa*	*1.2.17 Ahmad*
	1.2.9 Nathan	
1.2 Student (Abbreviated name)	*1.2.10 Kelly*	1.3 Curricula
1.2.1 Shirley	*1.2.11 Don*	*1.3.1 WQI*
1.2.2 Cathy	*1.2.12 Abby*	*1.3.2 WQII*
1.2.3 Charles		*1.3.3 Decomposition*

EventRecorder (ER) Charts of Modeling Actions and Practices

Because I used different grain sizes of the chunks of text (i.e. mode, event, and episode) in order to conceptually break a class session into manageable and meaningful chunks (Jordan & Handerson, 1995), I used episode as a unit of coding because each episode focused on one type of modeling activity, such as creating an object, a variable, or a relationship. Therefore, an episode was the minimum meaningful unit to reveal modeling practices. Furthermore, each episode began with a time mark so that I was able to enter the times of each episode into EventRecorder to create charts, as shown in Figure 3.7 and 3.8, in order to demonstrate the trajectory of student pair modeling actions and modeling practices.

Event recorder (ER) is a research tool that can help with data collection, analysis, and presentation (Berger, Walton, Wurman, and Jones, 1995). The ER charts in Figure 3.7 and 3.8 were created on a new version of ER with specific features that fit the needs of this dissertation. Over a period of several months, I worked closely with two programmers in order to develop the features. This new version of ER allowed me to add the duration of a modeling action or modeling practice under the line that denotes it. For example, a "2:15" under "Creating variable" means that creating the variable took two minutes and fifteen seconds. If a modeling action or practice happened with another intervention, such as a teacher's involvement, the ER program would show the codes at different places on the ER chart with the same time duration. Therefore, the graphs produced by the new version showed patterns better. A sample date set for creating the ER chart is shown in Appendix S.

Figure 3.7 shows that when a modeling action (such as modifying an object in plan mode) starts, it ends when the next modeling action (such as creating a relationship in build mode) starts. Therefore, the ER chart was able to demonstrate how long the modeling action "modifying an object" lasted. By the same token it could also show when a modeling practice, such as discussing a variable, happened and how long it lasted (Figure 3.8). The ER charts of a student pair or group's modeling actions and practices had the same time scale. This allowed me to compare the two charts and see how modeling actions and modeling practices are associated with each other. One way to do this was to print an ER chart of modeling actions on a transparency and lay it over the ER chart of modeling practices. The thin, dashed lines were added to help readers distinguish modes (for modeling actions) and the big categories of modeling practices (each with some subcategories).

Some practices or actions, such as "saving" or "deciding the course of action", happened only at a time point or in a short period of time instead of over duration of an episode. However, I had to code the whole related text chunk in NUD*IST and assign that code to that whole period of time on the ER chart because each time period on the ER chart has to have the starting point and end point in order to calculate the duration. "Saving" is a modeling action because it was important in preventing loses of models that the teachers had to keep reminding students to save. "Saving" without others' reminder actually showed student awareness of their progress as a sign of their metacognition. Nevertheless, several students still lost their models.

The Teacher_Peer_Researcher (TPR) intervention code was shown on both charts. It was on the modeling action chart because these were not student cognitive activities. However, they might greatly influence these activities. For this reason, I also put it on the modeling practices chart. The follow were the major interventions that were captured by this code:

1. Teacher reminded students about strategies for making the model, such as making a few objects, variables, and relationships, testing, and then expanding the model.

2. Teacher enforced the use of the program, such as saving and where to save similar to house-keeping.

3. Teachers or researchers were asked to help students with usability and conceptual issues.

4. Students interacted with peers from other groups.

On the ER chart of the modeling actions vs. time, the "other actions" code included actions that did not result in the direct change of a model, such as deciding the course of action, discussing something of cognitive or conceptual significance but without physical operation of the computer (e.g. discussing relationships).

On the ER chart of modeling practices vs. time, "the other practices" code included some actions that did not fit the definition of any modeling practice. These included technical problems, off-task, and saving. Given the space limit, the codes were abbreviated on the ER charts. Tables 3.10 and 3.11 list a comparison of the codes used and their abbreviated forms on the ER charts.

Table 3.10. Abbreviations of Modeling Actions Used on the ER Charts

2. Modeling actions*	2.3 Test	2.5 Irrelevant activities
2.1 Plan Mode (P_)	*2.3.1 Creating meter*	*2.5.1. Off-task*
2.1.1 Creating object (P_CreatObj)	(T_CreateMeter)	(Off-task)
2.1.2 Deleting object (P_CreatObj)	*2.3.2 Moving meter*	*2.5.2 Technical problem*
2.1.3 Modifying object (P_ModifyObj)	(T_MoveMeter)	(TechProblem)
Creating variable (P_CreatVar)	*2.3.3 Adjusting meter*	
	(T_AdjustMeter)	2.6 Possible supports
2.2 Build mode (B_)	*2.3.4 Minimizing or*	**2.6.1**
2.2.1 Modifying variable (B_ModifyVar)	*abandoning meters*	Teacher/Researcher/Peer
2.2.2 Deleting variable (B_DeleteVar)	(T_MinMeter)	(TPR_Intervene)
2.2.3 Creating relationship		*2.6.2 Discussing tool*
(B_CreateRel)	2.4 Meta-cognitive activities	*scaffolds*
2.2.4 Modifying relationship	*2.4.1 Pause and Rearranging*	(Dis_ToolScaf)
(B_ModifyRel)	*model layouts*	
2.2.5 Deleting relationship	(Pause_Rearrlayout)	2.7 Actions_Others
(B_DeleteRel)	*2.4.2 Saving* (Save)	

Table 3.11. Abbreviations of Modeling Practices Used on the ER Charts

3.4 Planning (PLN_)	3.3 Synthesizing (SYN_)	3.5 Reflecting & Monitoring (RefM_)
3.1.1 Stating goals	*3.3.1 Elaborating relationship*	*3.5.1 Seeking information*
(PLN_StaGoals)	(ANL_ElabRel)	(RefM_SeekInfo)
3.1.2 Discussing object	*3.3.2 Predicting*	*3.5.2 Gathering resources*
(PLN_DisObj)	(ANL_Predict)	(RefM_GathRes.)
3.1.3 Discussing variable	*3.3.3 Making connections(to*	*3.5.3 Deciding the course of action*
(PLN_DisVar)	*investigation and experiences)*	*(including asking reflective questions)*
3.1.4 Discussing	(ANL_MakCon)	(RefM_DecCAct)
relationships		
(PLN_Rel)	3.6 Evaluating (EVL_)	3.6. Publicizing and communicating
	3.4.1 Critiquing/interpreting	(PubC_)
3.5 Analyzing (ANL_)	*test results*	*3.6.1 Self-critiquing and reflecting*
3.2.1 Specifying object	(EVL_CriInter)	(PubC_SelfCri.)
(ANL_SpfObj)	*3.4.2 Identifying anomalies*	**3.6.2** Peer evaluating
3.2.2 Specifying variable	(EVL_IdenAno)	(PubC_PeerCri)
(ANL_SpfVar)	*3.4.3 Proposing solutions*	**3.6.3** Teacher evaluating
3.2.3 Specifying relationship	(EVL_PropSolu)	(PubC_TchrCri.)
(ANL_SpfRel)	*3.4.4 Carrying out solutions*	
	(EVL_CarOSolu)	3.7 Practices_Others

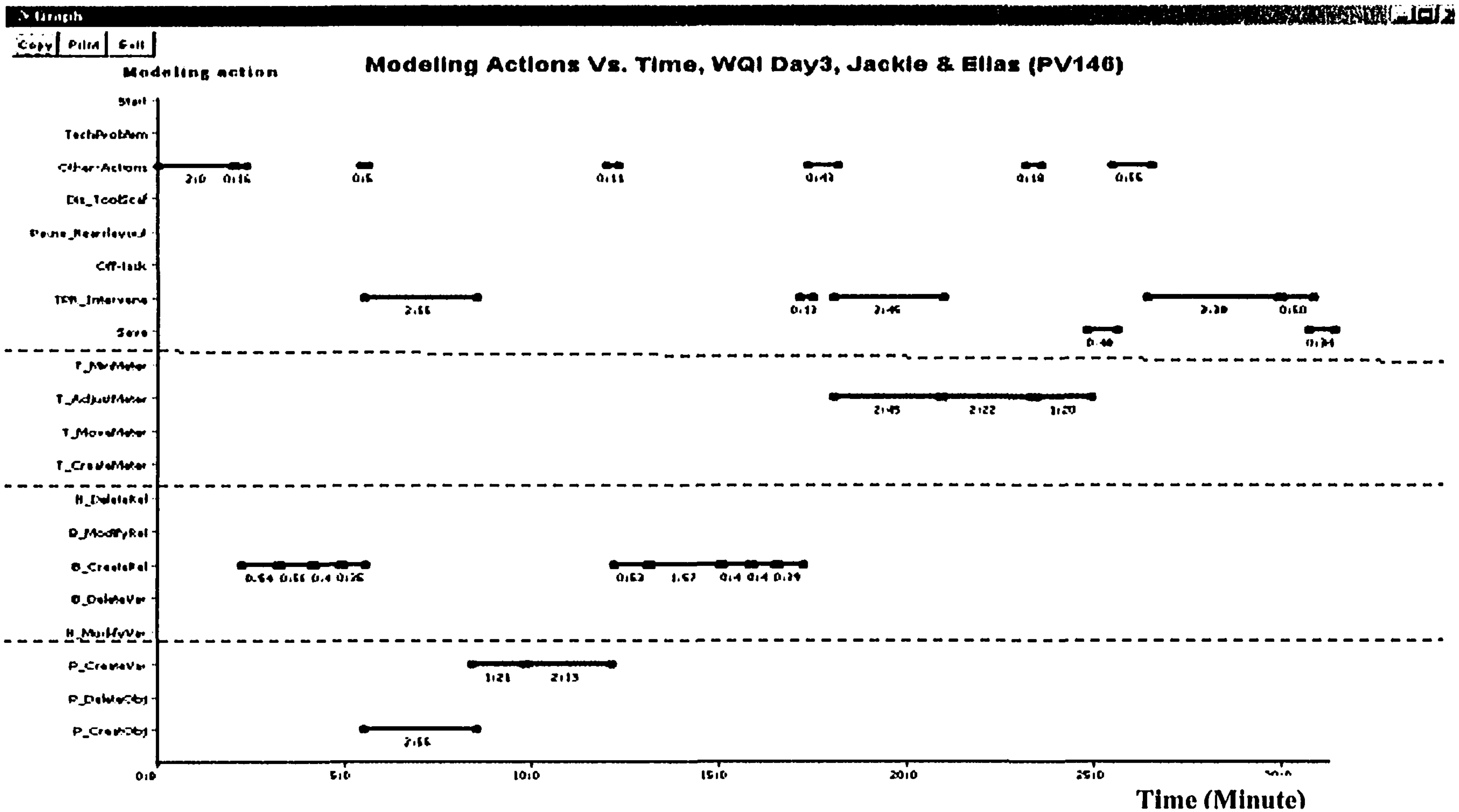

Figure 3.7. ER Chart of Modeling Actions of PV146: Student Pair Jackie and Elias

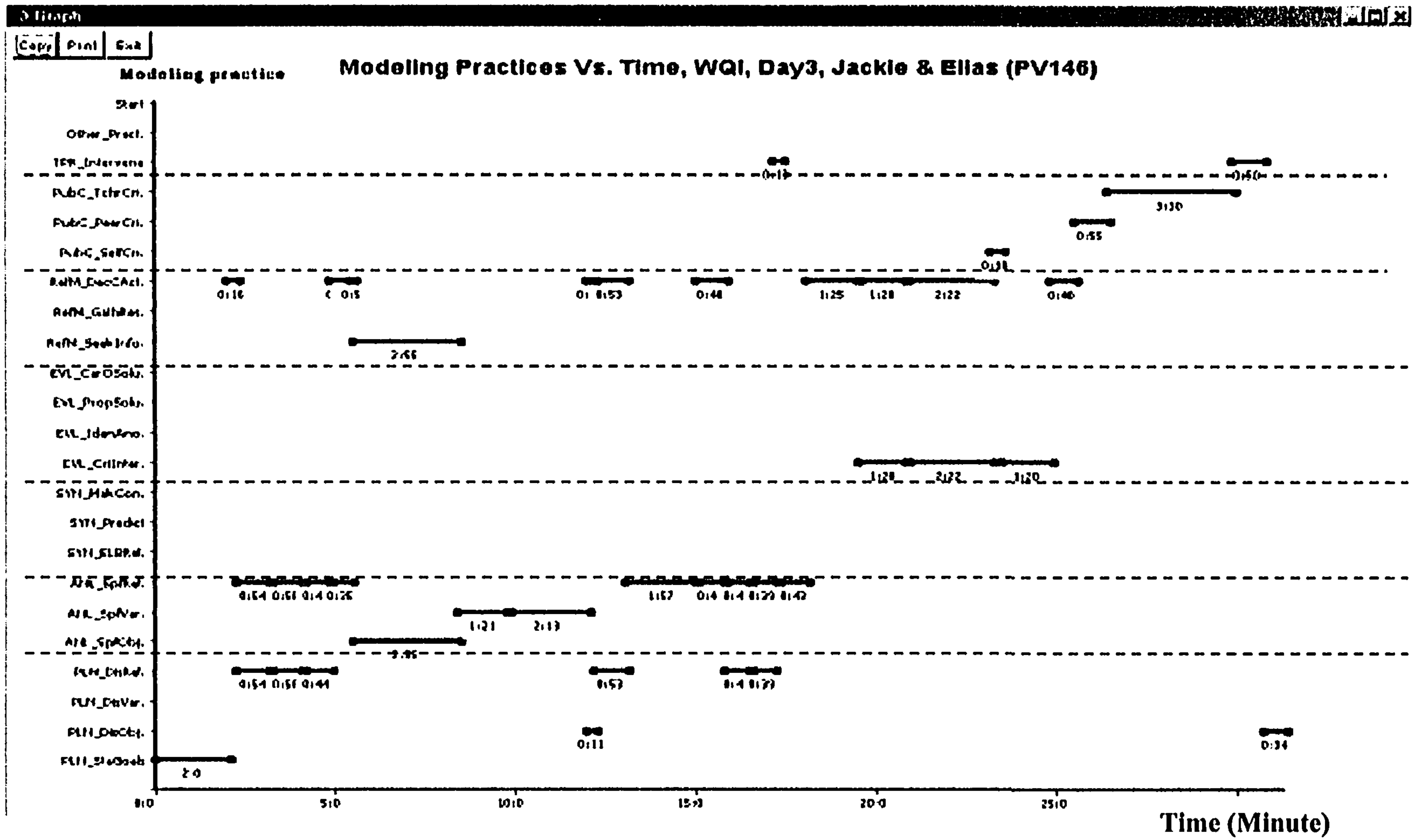

Figure 3.8. ER Chart of Modeling Practices of PV146-Student Pair Jackie and Elias

Based on the ER charts of modeling actions (Figure 3.7), modeling practices (Figure 3.8), and NUD*IST reports of modeling practices, after synthesizing the information for a class period, I created a summary of each class period (See Appendix N for an example). I then created cycle summaries (See Appendix O for an example) for each student pair of WQI. Assertions were made according to the summaries and across pairs.

A period summary included the following five aspects: modeling actions, modeling practices, metacognition, modeling knowledge, and collaboration. Modeling actions were what I saw from the process videos showing student computer screen operations. Modeling practices were inferred from student conversation and actions that revealed their cognitive activities. Metacognition refers to actions and statements that demonstrated how students monitored their progress, sought help, and gathered resources in order to move forward. Modeling knowledge is student understanding of models and modeling showed through student conversations and actions. Modeling knowledge might also be demonstrated from the use of the modeling software in terms of the underlying assumption of how the program worked. Collaboration captured how students allocated tasks and talked to each other in order to create a model. Each of the five aspects was decomposed into sub-questions in order to provide detailed accounts of those aspects. Tables 3.10 and 3.11 demonstrate the sub-questions I asked when analyzing student modeling practices and writing the class summaries.

When I wrote the cycle summaries for each student pair of WQI, I reviewed the same five aspects described above. Since I had to zoom out in order to capture a more complete picture of each pair's modeling practices during a modeling cycle, the summaries were more generalized and condensed and did not include all the excerpts.

I also looked at each modeling practice from another perspective in order to better answer the research questions. As shown in Table 3.12, I asked three questions for each modeling practice: When did the practice happen? How did it happen? And Was it helpful for student learning? The category "When did a practice happen?" showed the situations in which students were able to perform a modeling practice. The modeling practice could be facilitated by the scaffolds of the software. I also looked at whether a modeling practice became more automatic even without scaffolds. The question "How did model practices happen?" showed whether a modeling practice was efficient, whether students were purposeful, and whether the practice was meaningful to the students. Further, as shown in Table 3.13, I also looked at whether a modeling practice helped student learning. For example, did a practice deepen student understanding of content or modeling with our purposeful design? Looking at the above aspects over time allowed me to make a more purposeful conclusion with alignment to the "design experiments" approach for specific outcomes.

In addition to the six modeling practices, I also reported results on the nature of student metacognition, modeling knowledge, and collaboration using a similar format to that described above. In order to answer research question three, accumulated evidence was collected and narratives were created using the similar approach. The narratives were about the curricula, software, and teacher instruction and interventions.

Table 3.12. Guiding Questions for Analysis of Student Modeling Practices

Practices	Questions for looking for patterns	Examples
Planning	1. Do students have a driving question or scenario for what they want model? 2. Do students have a plan about what they want to build? 3. Do students discuss their ideas before they make decision on model construction?	1. Students look for images purposefully. 2. Obtain ideas about objects, variables, and relationships by referring to their notebooks; 3. Making decisions before building according to discussion and agreement.
Analyzing	1. How do they use the images built in the program to help them build and think about objects and variables? 2. Do they make use of all the required fields (e.g. description of objects, variables, and the "because statement" box for relationships) and understand the purposes of those requirements?	1. Planning on objects, variables, and relationships is a process of analyzing; 2. Planning on what should be within an object, variable, or relationship is also analyzing, such as naming a variable, deciding initial value, and describing the variable.
Synthesizing	1. Is there an alignment of student driving questions or foci of their models and the models' content? 2. How and in what conditions does synthesizing happen? 3. How does synthesizing help students in constructing and revising their model?	1. It happens when students plan their relationships. 2. It is more synthesized when students elaborate on their relationships in terms of their driving question or focus.
Evaluating	1. When does evaluating happen? 2. What criteria students do use to evaluate their model?	1. When students pause and arrange variables and relationships and get revision ideas; 2. When they exam the details of an object, variable, or relationship; 3. When they test a model. 4. When they present, reflect, and receive feedback.
Reflecting and monitoring	1. What are the strategies students use for monitoring and reflection? 2. How do these metacognitive practices help students?	1. Pausing and rearranging the model layout or visualizing the model. 2. Being aware of their progress; 3. Seeking information 4. Using notebooks and other resources.
Publicizing & communicating	1. How does the practice happen? 2. What are the consequences of this practice?	1. Articulating and elaborating their ideas 2. Collaborating; 3. Commenting and receiving feedback

Table 3.13. Guiding Questions for Writing Class Summaries

Aspects	Questions
Modeling actions	1. What happens throughout the whole class period that relates to model construction, test, or modification? 2. What episodes illustrate the detailed modeling actions that could be used as evidence for findings?
Modeling practices	1. How is planning, analyzing, synthesizing, evaluating, reflecting and monitoring and publicizing and communicating demonstrated during the class period. 2. What episodes illustrate the detailed modeling practices that could be used as evidence for findings?
Metacognition	1. How do students monitor their progress, such as save? 2. How do students seek help? 3. How do students gather resources?
Modeling knowledge	1. Do students understand the purpose of a model and modeling? 2. Do students understand how to give object and variable names and descriptions? 3. Do students understand how to make a relationship and write "because statement"? 4. Do students understand how to evaluate the quality of a model?
Collaboration	1. Are students engaged and how much do they contribute to a model? 2. How do students allocate the tasks of being a typer and/or a mouser? 3. Do students demonstrate good rapport, such as asking for feedback, listen to the partner, attitude to suggestion, and manner in managing argument?

NUD*IST Coding and Analysis of Classroom Video Transcripts

As mentioned above, there were three different types of classroom videos. Verbatim transcripts were created from class videos of teacher instruction in the first modeling class of each of the three modeling cycles. When a teacher was demonstrating the use of Model-It, I coded the transcripts in NUD*IST using the same codes of modeling actions and modeling practices that are listed in Tables 3.5 & 3.6. The purpose for coding these video transcripts, however, was not to characterize or describe student modeling practices. The summaries (See Appendix P for an example) of such classroom videos were used to see how teachers modeled those modeling practices. The video transcripts allowed me to see how teacher instruction provided a context for student modeling practices. Student modeling practices might have been influenced by teacher instruction. The transcripts of the classroom videos helped interpret and triangulate the findings from the process video analysis.

For the same reason, summaries of the whole classroom videos (See Appendix Q for an example) and verbatim transcripts of student pair class presentations were also used to triangulate assertions from analysis of process videos. Summaries (See Appendix R for an example) of classroom videos of student pairs presenting their models revealed not only what was included in a model and what the model was about, but also the rationale for student choices that might explain the results found from the process video analysis.

The classroom videos were not transcribed for classes in which students were creating computer-based models. They provided supplementary data and were checked when necessary.

Synthesizing and Making Assertions

Based on the class and cycle summaries of modeling actions and modeling practices obtained from the above analytical processes, I generated assertions. An assertion includes the following steps: First, I provided an overview of a modeling practice, such as analyzing practices, across pairs. Then I provided more interpretation of the results. And third, I used quotations or examples as evidence from the data sets to support the assertions. After reporting the nature of an analysis, I summarized the major assertions based on what I presented.

Repeat Analysis of Data of WQ II and the Decomposition Unit

Using the same procedures shown on Figure 3.5, I coded the process video transcripts for each pair of target students in WQ II and the decomposition units. I then created NUD*IST reports of modeling actions and practices for each of the process video transcripts. I also created ER charts of modeling actions and modeling practices for each student pair as I did for WQI. Based on the NUD*IST reports and ER charts, I created class summaries for each target student pair or group of a class period, and cycle summaries for each target student pair or group of WQ II and the decomposition unit. I compared the session summaries and looked across pairs for WQII and the decomposition unit comparing these to the summaries of WQI in order to answer research question two.

I also coded the classroom video transcripts of teacher instruction. Then, based on the NUD*IST reports, I created summaries about how teachers provided instructions to support student modeling practices and what students presented about their models for confirming and triangulating the assertions from the process video analysis. Student final presentations for WQII and the decomposition unit were summarized in order to create a holistic view of student final models. The classroom videos of the computer-based modeling classes were used as a supplementary data source.

Generating Assertions

Assertions were narratives about patterns that emerged from the analysis of the NUD*IST reports of the PV and CV transcripts, ER charts, and later the reduced class and session summaries. The summaries of WQI, WQII, and the decomposition Units of

Process videos and Classroom videos became the databases from which I generated descriptions and assertions at each cycle of student computer-based modeling. By creating and reviewing all the summaries and reports, I generated assertions through induction. For example, by looking at both the Process videos and the Classroom videos, I found that both teachers' instruction and the modeling program helped student analyzing practice.

In order to help me focus on evidence that supported the assertions to answer my research questions, I asked a series of questions, as listed in Tables 3.10 and 3.11 in terms of my codes of modeling actions and practices. The series of questions helped me characterize modeling practices and search for changes in student practices over time. I made my assertions collectively across the six pairs or groups of target students. In the decomposition unit, target students were either swapped or totally changed. However, across the six pairs, they were still representative of the student population that I investigated.

Evaluating the Quality of Student Modeling Practices

According to "Design experiments" methodology, it is necessary to provide criteria to evaluate the implementation of a design (Collins, Joseph & Bielaczyc, in press). In a narrow sense, the focus of this study was about student modeling practices. Therefore, three criteria were used for evaluating the quality of student modeling practices: Efficiency, meaningfulness and purposefulness. The judgment was made according to the context in which a practice occurred. First, an *efficient* practice (Efficiency) is a practice that was used productively in generating a model's components (i.e. objects, variables, or relationships). If a student pair generated more objects, variables, or relationships within one mode rather than jumping back and forth between modes, it meant they were working more efficiently. Usually the judgment of efficiency was made by using the students themselves or their peers during the same class period. During the decomposition unit, Elias's group created 13 objects, 13 variables, and 11 relationships in one class period. This showed that they created a model efficiently comparing to the number of 5 objects, 5 variables, and 7 relationships created by the other pairs of target students in the same class. However, efficiency has to be considered in combination with meaningfulness and purposefulness to really show the quality of student modeling practices.

Second, a *meaningful* practice (Meaningfulness) means students were confident and understood the decisions they made. It was not unusual to see from the process videos that students were hesitant and stated that they were not so sure but they still did something. These instances showed that they were not very confident and so the practice they performed was considered as less meaningful. A practice seemed to be meaningful when the decisions were based on student experiences instead of random guessing. A meaningful practice also means that students were taking control of their modeling actions and thinking rather than just following the teacher's instruction (Deci & Ryan, 1987; Lepper, 1988; Papert, 1991). For example, Kelly and Nathan assigned the initial value of the STREAM: DO variable of their model during WQI. They assigned the value as high because they recalled that the DO level of their stream was about 105 to 110. If a student pair only followed what the teacher told them or accepted ideas from other students without making strong arguments to support the decision, the practices are not meaningful to students. Student pair Abby and Don created 9 objects but their model became unmanageable on Day 4 of WQI. Although they were able to make use of all the images from the image palette, they did not understand how to name a variable, assign an initial value, and provide a description for it. They frequently sought help and tried to understand what a variable was and what their model was about. They each had a focus in their mind. They finally gave up the idea of fixing their model and they created a new model in 18 minutes when Abby decided to create a model about DO and make decisions with Don's agreement. This time, the modeling practices seemed to be more meaningful to them because their model was much more accurate and complete in representing the phenomenon they investigated. In contrast, the model of decomposition that Elias' group created was less synthesized and accurate in reflecting the real phenomenon although they were efficient in creating it.

Third, a *purposeful* practice (Purposefulness) means that student modeling actions and conversations were not random but considered the driving question or the relationships in the model when determining objects and variables. A purposeful modeling practice usually was accompanied by synthesizes or prediction in terms of the whole picture of a model in production. For example, when asked on Day 2 of WQI, Kelly and Nathan told the teacher that they were going to build a model about trees and DO. Therefore, for almost every object and variable, they talked about how it might be related to their focus. At the very beginning on Day 2, Kelly asked a researcher how to add more variables to (object) TREES because they had a lot of variables for it. The first two objects they built were TREES and STREAM because those were what they had planned. Therefore, their practices were purposeful because they understood what they needed based on solid reasons.

In order to answer research question one, twenty-four class-period summaries were created for the twenty-four process video transcripts. The summaries were based on NUD*IST reports and ER charts. Two ER charts were created for each modeling period unless a modeling period was less than ten minutes. Altogether, 18 X 2 = 36 ER charts were created for both modeling actions and modeling practices for the six target student pairs from the three classrooms of WQI. Six session summaries were created for the six target student pairs. Three Classroom video (CV) transcripts of the first class of teacher introduction in each modeling cycle and six CV transcripts for the six class presentations were analyzed and summarized.

In order to answer research question two, nineteen class-period summaries were created for WQII. Again, the modeling period summaries were generated according to the NUD*IST outputs and 19 X 2 = 38 ER charts created for both modeling actions and modeling practices. Six session summaries were created for the same target student pairs, respectively. For WQII, three Classroom video (CV) transcripts of the first class of teacher introduction in the modeling cycle and six CV transcripts for the six pair class presentations were also analyzed and summarized for WQII.

For the decomposition unit, fourteen class-period summaries were created. They were based on the NUD*IST outputs and 14 X 2 =2 8 ER charts for both modeling actions and modeling practices. Six session summaries were created for the six target student pairs or groups. Again, three Classroom video (CV) transcripts of the first class of teacher introduction in the modeling cycle and six CV transcripts for the six class presentations were analyzed and summarized.

Holistic View of the Class Environment

As stated before, for this type of "design-based" research, it is very important to create a profile of the classroom environment in order to help others who want to enact the curricula. Using NUD*IST reports of the CVs of teacher instruction, I explored how the teachers demonstrated modeling actions and practices, and provided instructions. I also generated NUD*IST reports of the process video transcripts by using the "review code" feature. In NUD*IST, I reviewed the following codes:

The first code was "TPR intervention", which stands for teacher, researcher and peer intervention. The instances of this code revealed how the teachers, researchers, or peers intervened and interacted with a target student pair during the modeling processes.

The second code was "peer evaluating" and "teacher evaluating". These codes showed how teachers, researchers, or peers provided feedback and comments when students presented their models to others or the whole class. It also revealed the outside influence on student modeling practices.

The third code was "Discussing scaffolds". Instances of this code showed student discussion and understanding of the design of the modeling program as well as their modeling knowledge.

As mentioned above, from each of the three modeling cycles (i.e. WQI, WQII, and decomposition), three CVs from each of the three classes were analyzed. Six CVs for the six presentation were analyzed.

In addition to the primary data, student notebooks and booklets of their investigations were referred to when necessary although they were not analyzed systematically. All student final models were replicated, and the intermediate models of each pair from each class period were replicated. Altogether, 6 X 3 = 18 final models and 56 intermediate models were replicated. Again, they were used as supplementary data as needed.

Using the NUD*IST outputs described above, I was able to create a profile of how the curricula, teachers and other more knowledgeable individuals, software programs, and resources might have impacted student modeling practices. Summaries and narratives were used to answer research question three. Characterization of the class learning environments, thus, helps interpret and triangulate the results of the analysis of the process videos as well.

Quality Control

The following strategies were used to ensure the quality of analysis: First, the study of the first enactment allowed me to be familiar with the research setting. Second, the iterative interaction with different data sets allowed me to confirm or disconfirm my assertions. Third, thick description of the research processes and careful documentation allowed others to inquire and provide feedback at all stages of the research process. Fourth, close collaboration with my research team allowed me to receive comments and feedback in a timely manner.

Understanding the Setting

In order to be able to adapt to the research setting, a researcher needs to spend enough time in context to avoid using unusual or atypical events to make inferences. I entered the research site in fall, 1999, and our study for the first enactment concluded in summer 2000 (Zhang et al., 2001). This gave me time to become familiar with the school environment, the teachers, the students and the school and class culture. I am from a different cultural background. I tried hard to utilize my knowledge and experience as a former science teacher and science teacher educator. With more than one year's involvement in the research site, I gradually immersed myself in the class lives of the participants.

As we did for the first enactment of the design, other two student researchers and were introduced to students in the three classes that we observed at the beginning of their science classes as well as their first year in middle school. We briefly introduced ourselves, the purpose of our study, and the way we worked in the classes based on our university's IRB (The Behavioral Sciences Institutional Review Board) approval. Students also asked questions. Our prolonged engagement in the classes, an 8-month period, and talking to students before classes, during breaks, and during our interviews with target students helped us to be minimally intrusive. In one special case, I captured one pair's conversation when they were stuck in the modeling process from a process video; they discussed whether they should address me using my first name. We were actually considered as their technical supporters when using the computer-based modeling program as well as content experts for information seeking.

During three rounds of data collection (WQI, WQII, and the decomposition unit), I had spent enough time in the context to capture recurrent patterns. I also talked to teachers frequently about what I thought about what I had observed for "member checking." Finally, multiple sources of data (i. e. classroom videos, process videos, student interviews, science reports, and models) used for triangulation also helped to establish credibility.

Iterative Interaction with the Data Sets

The intensive interaction with the data sets, especially the primary data source of the process videos (PVs) ensured the validity of the analysis. First, I was one of the transcribers who added student modeling actions but also went through all the PV transcripts and wrote the preliminary summaries for each pair of each modeling class period. The data management and reduction process took about four months. Second, when I coded the PV transcripts, I needed to go through the data again and had to think thoroughly in order to assign appropriate code(s) to an episode. Therefore, I was able to write summaries for each pair of every modeling period again. This time I did not just augment my preliminary summaries, but started fresh and did all the summaries on paper. I use these summaries to compare the results of my third interaction with the data from the generated ER charts. I had to prepare the data based on the time marks at the beginning of the episodes (See Appendix S for an exemplar data set for an ER chart). I also needed to make sure that my NUD*IST coding was correct so I read the whole text a third time. I went back to specific tapes when something was unclear. After creating the ER charts, I reviewed my summaries from the NUD*IST coding process and added more quotations as needed. After reading the ER charts of modeling actions and modeling practices for each pair in a class period, I combined the summaries from NUD*IST coding processes and my preliminary summaries from my transcribing process. I also made cycle summaries for each pair (Appendix O). Therefore, three rounds of intensive interaction with the data sets helped me to confirm and disconfirm my predicted findings with the accumulated evidence. Thus, the interaction also improved the validity of the assertions.

Thick Description and Purposeful Sampling

Thick description details context information and dynamics with the context. In the study, I provided a detailed description of the curricula, the teachers, the school characteristics, the class culture, and target students (e.g. ethnicity, socioeconomic statues, and achievement level).

This technique required sites and informants to be optimally informative. Since my study was only about students in an independent school, a purposeful sample was done to assure that the target students were "representative" according to the researcher's observation and help from the teachers. Target students in my study, overall, had mixed gender, ethnicity, and achievement levels.

Collaboration with Research Team

I was supervised by senior investigators, shared data with other researchers and discussed and worked as a research group for transcribing and coding to improve intra-rater agreement. This was the way that our research group worked for our first enactment. The study enabled me to be able to work independently on analyzing my dissertation data while it still assured the validity of the analysis. I also talked to teachers in our debriefing meetings or by email. Since video recording became routine with the presence of the researchers, I was able to record my data in a relatively nondisruptive way.

Two other graduate student researchers and the senior researcher who were also involved in this project examined the codes, descriptions, findings, and assertions generated to assure validity. In the last step of data analysis, I shared my findings with the teachers. After assertions were generated, I went back to my data to look for more evidence to confirm or disconfirm my assertions.

In summary, the study was conducted with purposeful planning, clear goals, multiple data sets, and collaboration in order to assure its quality.

Limitations of the Study

I relied on student behaviors, discourse, social interaction, as well as artifacts to investigate their cognitive activities. For students who were not good at using these ways to externalize their understanding, their cognitive growth might be underestimated.

This study traced student modeling processes; it did not have data from before students worked on computer-based modeling. Although I had been observing the teachers' teaching at the same school in the previous pilot study and used a parallel study (Wu, 2002) to triangulate my interpretation, my role as an "observing participant" might not be quite "immersive" (Moschkovich & Brenner, 2000).

Class sizes were small and students were more academically capable than average in this independent school in a suburban area. As Christie (2002) argues, aspects of practices that emphasize problem-solving, experimentation, inquiry, and other hands-on activities, which are more often found in suburban settings, hold quite different theories of teaching and learning, and quite different definitions of success and failure. Means, Penuel and Padilla (2001) argue that these qualitative differences in urban and suburban pedagogies continue to reveal themselves in technology-supported practice. Therefore, the differences might also affect the applicability of this study.

Given the time constraint, it was impossible to do a systematic analysis of all the data sets, although I have largely finished the data management. Therefore, the replicated student final models and their intermediate models, interviews about student modeling knowledge, and student notebooks and booklets were used only as supplementary data.

CHAPTER IV

RESULTS

The order for reporting the results is from research question one to research question three. The first research question addresses student modeling practices during their initial modeling cycle (WQI). The second research question discusses the changes of student modeling practices in the second (WQII) and third (decomposition unit) modeling cycles. The third question answers what features in the learning environment facilitate student modeling practices. For each modeling cycle, I report the results collectively across the six pairs (or groups) of target students according to the major modeling practices: planning, analyzing, synthesizing, evaluating, and publicizing. In addition to the modeling practices, I also report on some other dimensions of student learning that are involved in their modeling practices: student metacognition, inquiry experiences, content knowledge, modeling knowledge, and collaboration. Since the practice of reflecting and monitoring overlaps with metacognition, the results are reported with those of metacognition.

At the end of the second and third modeling cycle, I provide comparative accounts to review the changes in student modeling practices over time in order to answer research question two. Consistent with the report for WQI, I also provide a comparison of changes in student inquiry experiences, metacognition, content knowledge, modeling knowledge, and collaboration in WQII and the decomposition unit.

The third research question addresses the major elements in the learning environment that might have promoted or constrained student modeling practices. The results for this question can help interpret what was found for research question one and two. They also provide evidence for revising the design of the learning environment.

What Are Student Initial Modeling Practices?

The first research question addresses what happened when students were involved in modeling practices for the first time. Table 3.13 illustrates some guiding questions that were used when looking at student planning, analyzing, synthesizing, evaluating, reflecting and monitoring, and publicizing practices. These questions were used consistently across the six pairs.

Planning Practice

Planning practice reflects student conversation about planning what to build in a model before they had any actions. Plan practice began after teachers gave students homework. When the teachers encouraged students to make use of their notebook, CompBook, or booklets[5], teachers expected students to have a plan of their model in writing. Planning practice also occurred during the process of model building when students discussed and decided what to build in their models.

Student initial planning was done before the first modeling class period so it was not captured by the data. According to the process videos, it seemed that all student pairs

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[5] CompBooks, and booklets are the terms the teachers and students used. They were their notebooks that student put the background information for investigation, records of investigation, data analysis records, and conclusions of their investigations.

had some kind of plan for their models. However, one important aspect of a planning practice is the recognition of driving question and no student pair mentioned their driving question or focus before being asked. Perhaps this was because students had a plan and it was not necessary to talk to each other about what they were supposed to build. It was also possible that the importance of driving questions simply did not occur to the students.

Most student pairs were able to tell the basic ideas of their driving questions when asked, except Lisa and Shaw, but the driving questions or foci of models evolved with the progress of their modeling processes. For example, Shirley said that their driving question was "How do different things affect the level of thermal pollution?" (PV134, 0611). They changed it to "How do people affect thermal pollution?" after the teacher Alice provided feedback. As shown in the following excerpt (PV137, 0350), students Jackie and Elias only had a basic idea about their model (Lines 3-4), but they refined their idea of the model later.

(PV137) 0350 A researcher asks student driving question.
Students say their computer is frozen.
Jackie: oh, the plants...
Like how do plants evolve in the water cycle.

On the next day (Day 3), Jackie mentioned their goal of creating a "general model" instead of a model of turbidity (PV146, 0530 and 0946).

Lisa and Shaw could not say what their driving question was even on Day 3 (PV145) when asked. Lisa later mentioned her driving question to Shaw "my driving question is how houses affect water quality." (PV145, 1115). However, Shaw did not confirm it so it did not become their shared focus. Interestingly, the idea of creating a model around a houses and stream was first proposed by Shaw. According to the classroom video of their first modeling class (CV129), at the end, Shaw asked the teacher "Can we do like a house or stream?" the teacher answered "You do anything you want, a house would be fine, and think about what are the variables." Therefore, Shaw did not keep this idea in his mind when they were creating their model because he could not state their driving question when asked. Given the complexity of computer-based modeling, students might be overwhelmed by all the new information in terms of content knowledge, modeling knowledge, and learning about the software program. Further, this pair also had some difficulties with collaboration, as I discuss later.

Planning is a process of sharing understandings. An interesting example of this occurred with student pair Kelly and Nathan (Figure 4.1). Their focus was to describe the effects of trees on turbidity. They planned their model in their notebook and had little discussion when creating the object TREES (#1) and its five variables (#2). However, during the modeling session, when they were creating objects, variables, and especially relationships that were not fully discussed, they engaged in rich discussion of variables (#3) and relationships (#4).

Figure 4.1 shows the activities of second day of the student initial modeling cycle in which Kelly and Nathan actually started building their first water quality model. They probably had done some careful planning during the previous class period because another target pair, Abby and Don, in the same class had spent about 11 minutes on modeling during the previous class. Kelly and Nathan spent a short time (1:16) creating their first object TREES although they also needed to become familiar with the modeling program. They then created four variables for the object in a relatively short period of time (about six minutes total). No planning happened before they created the second object STREAM. Then Nathan suggested creating more objects that had not been planned; therefore, the planning actually resulted in a quite different but reasonable solution from the idea that was originally planned. Kelly proposed PEOPLE but Nathan suggested CAR as the next object (Lines 7-8). The following excerpt shows the episode (PV140, 1507).

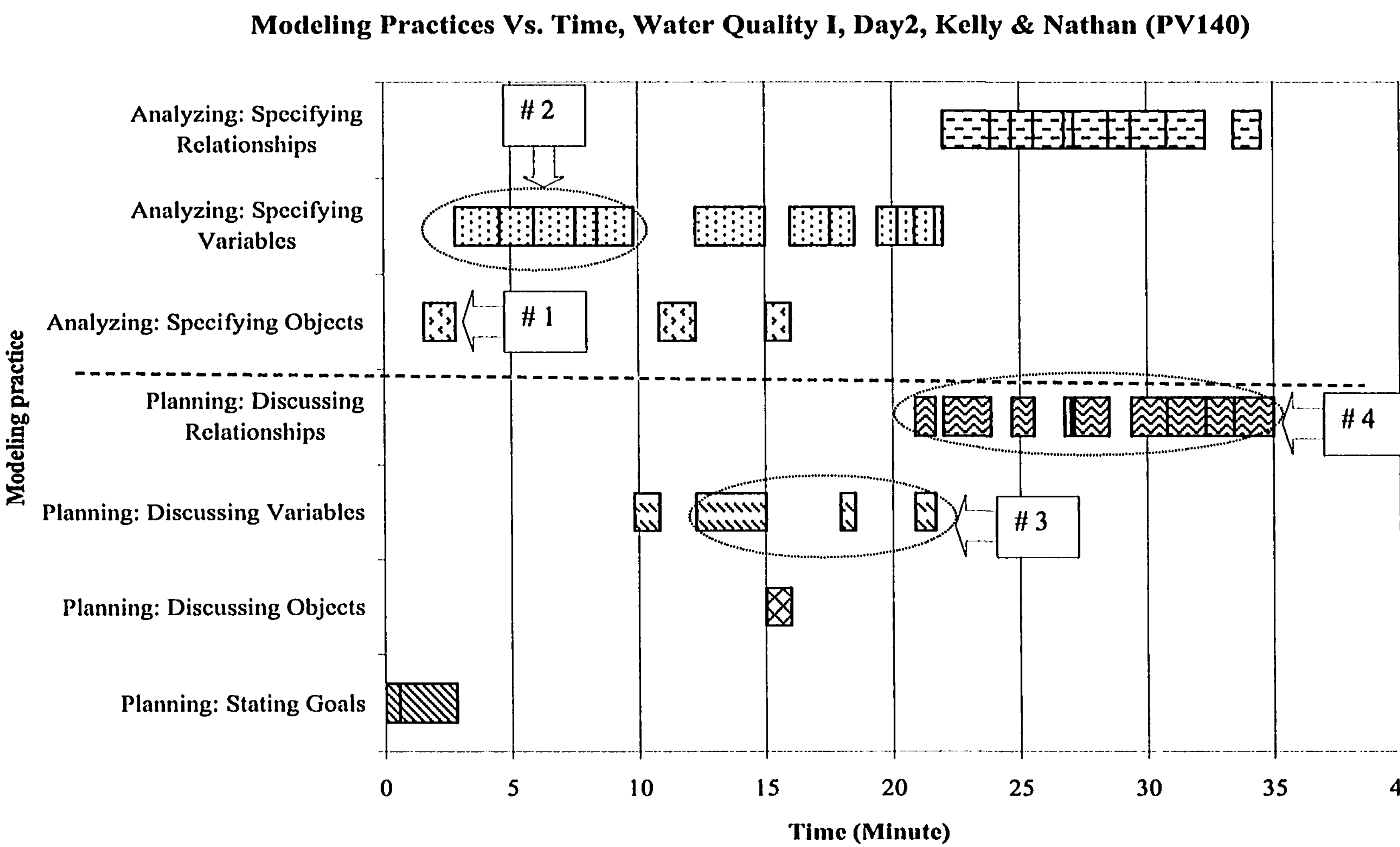


Figure 4.1. Modeling Practices (PV140 of Kelly and Nathan)

In the following episode (PV140, 1507), they actually ended up using PARKING LOTS as the object for describing the effect of cars because the cars that were parked in parking lots could leak oil or other chemicals to pollute the water. Without careful planning like this, students might not have been able to express their ideas accurately.

(PV140) 1507 Kelly: Ok, what are we going to do? Build?
Nathan: we probably should have one more object, shouldn't we?
Kelly agrees.
Nathan: do we have any more?
Kelly: we did not put like people, they can cut down trees,
I mean not only by our stream…might pollute.
Should I put people?
Nathan: I do not know. Let see "car".

On the other hand, modeling without a good plan might bring more frustration and make the modeling process less efficient as shown in Lisa's case. The following excerpt is another example showing the importance of planning. On Day 3, Don answered that their driving question was "How do humans affect water quality?" when asked. However, Don had never talked about their driving question with his partner, Abby. Don suggested the question by making an argument that everything in their model was affected by humans (PV148, 0228).

Abby was less sure about the driving question that Don proposed. She asked another classmate for help saying that she wanted to create a model of how things affect DO (PV148, 2351). At the beginning of their modeling, it seemed to be an image-driven process because they used up all six images on the image palette and created nine objects. This model (Figure 4.2) without a focus finally got out of control because they were not able to explain the model when they prepared to present it to the whole class. After failing to modify their model during the first half of Day 4, Abby took the initiative and created a model with the permission of the teacher and the agreement of Don. She created a model in eighteen minutes and they presented this fully functional model to the class the next day (Figure 4.3). It seems that during the struggling, Abby planned and reorganized her ideas with her own driving question with the help of the visualization and her conversation with her partner and the teacher.

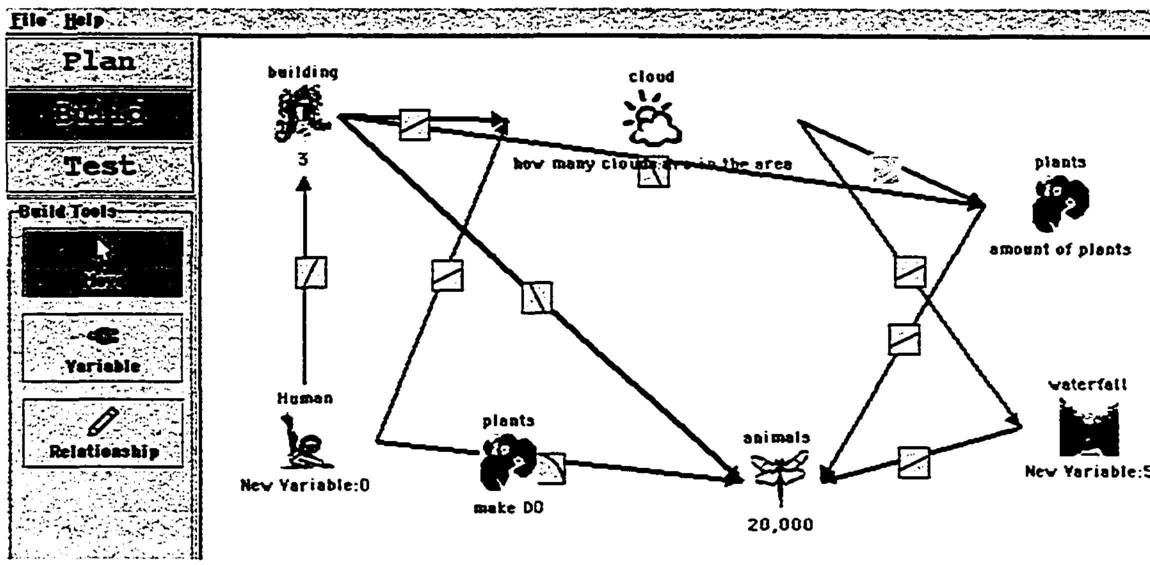


Figure 4.2. The Intermediate Model that Abby and Don Rejected

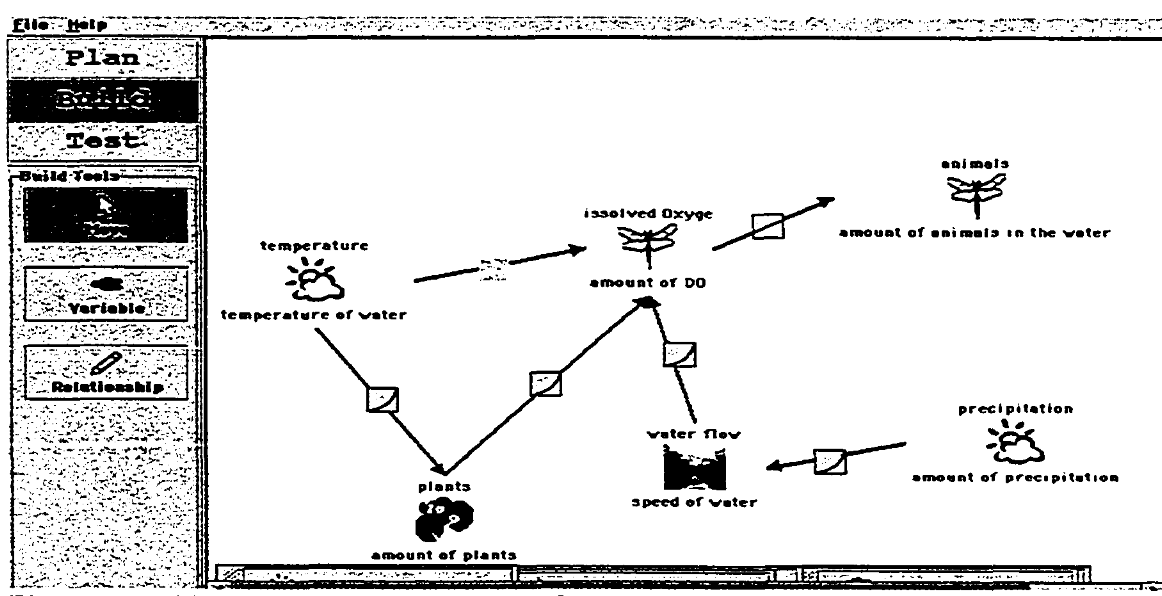


Figure 4.3 Abby and Don's Final Model of WQI

In summary, a driving question or focus is very important for students to purposefully create a model that makes sense to them. Good planning before modeling helps smooth the process of model building. Planning during modeling seems to provide the opportunity for students to communicate with each other to develop a shared understanding of a phenomenon.

Analyzing Practice

Analyzing practice reflects student modeling actions and conversation about the different components of a phenomenon. As shown in Appendix A, the modeling actions prescribed by the modeling program led to analyzing practice. Deciding on objects, variables, and relationships during the course of planning and building using the scaffolds in Model-It was a process of analysis because students had to think about their models in terms of different components. Furthermore, analyzing also occurred when deciding on the details of a model's components (i.e. an object, variable, or a relationship), such as naming an object or variable, providing descriptions, deciding the initial value of a variable, specifying a relationship, and so on.

In general, students were able to perform analyzing practice using the scaffolds, such as the object editor, variable editor and relationship editor. It was also a process of making sense when everything was new to the students. For example, the following excerpt illustrates how students decided on a variable name and description (PV133, 0813). The variable name *many people* [Line 2] is not a measurable trait of the object PEOPLE. Students later modified it *to the amount of people*. Students proposed a series of descriptions [Lines 3-6] and finally decided on the description that was explanatory, more meaningful, and relevant to the focus of their model [Lines 7-10].

1 (PV133) 0813 ...(They then discuss the description.)
2 Charles: The variable is (PEOPLE) many people.
3 Simon: Old people?

Charles: Big people. Description?
Simon: Fat people.
Charles: People dump chemicals.
Simon: (while typing)...people...Have come to the park and...
Charles: Have come to the parrrrk? Oops, here we go.
Simon types the description in: people who come to the park and dump chemicals into the water.

How students performed analyzing practice seemed to be affected by how the teachers demonstrated the use of Model-It. I use Day 2's analyzing practices as examples because when students went through the whole modeling cycle, their analyzing paths varied considerably, with many unpredictable factors. The path of analyzing practice on Day 2 for Charles and Simon (Figure 4.4) and Cathy and Shirley in class I was similar to that of their teacher (CV126). When demonstrating the use of Model-It, teacher Alice in Class I first created the objects (#1), then the variables (#2), and then the relationships (#3). She went through one cycle of creating and testing (#4) a model in one class period. The students were also those who had good planning prior to the modeling cycle.

Students were constrained by how the teacher demonstrated the use of Model-It in classes II and III. On Day 2, student pairs Lisa and Shaw, Jackie and Elias, Kelly and Nathan, and Abby and Don basically followed the order of one object, one or more variable for it; then another object, then one or more variables for it. Students created relationships on Day 2 after teacher Carol showed them how to do it. On one hand, this approach reduced student cognitive load. One the other hand, this might also bring some difficulties to students. For example, Lisa did not know how to delete a variable on Day 1 because they had not learned how to find the variable in build mode yet. She then deleted the object that the variable attached to so that she also lost other variables she wanted to keep.

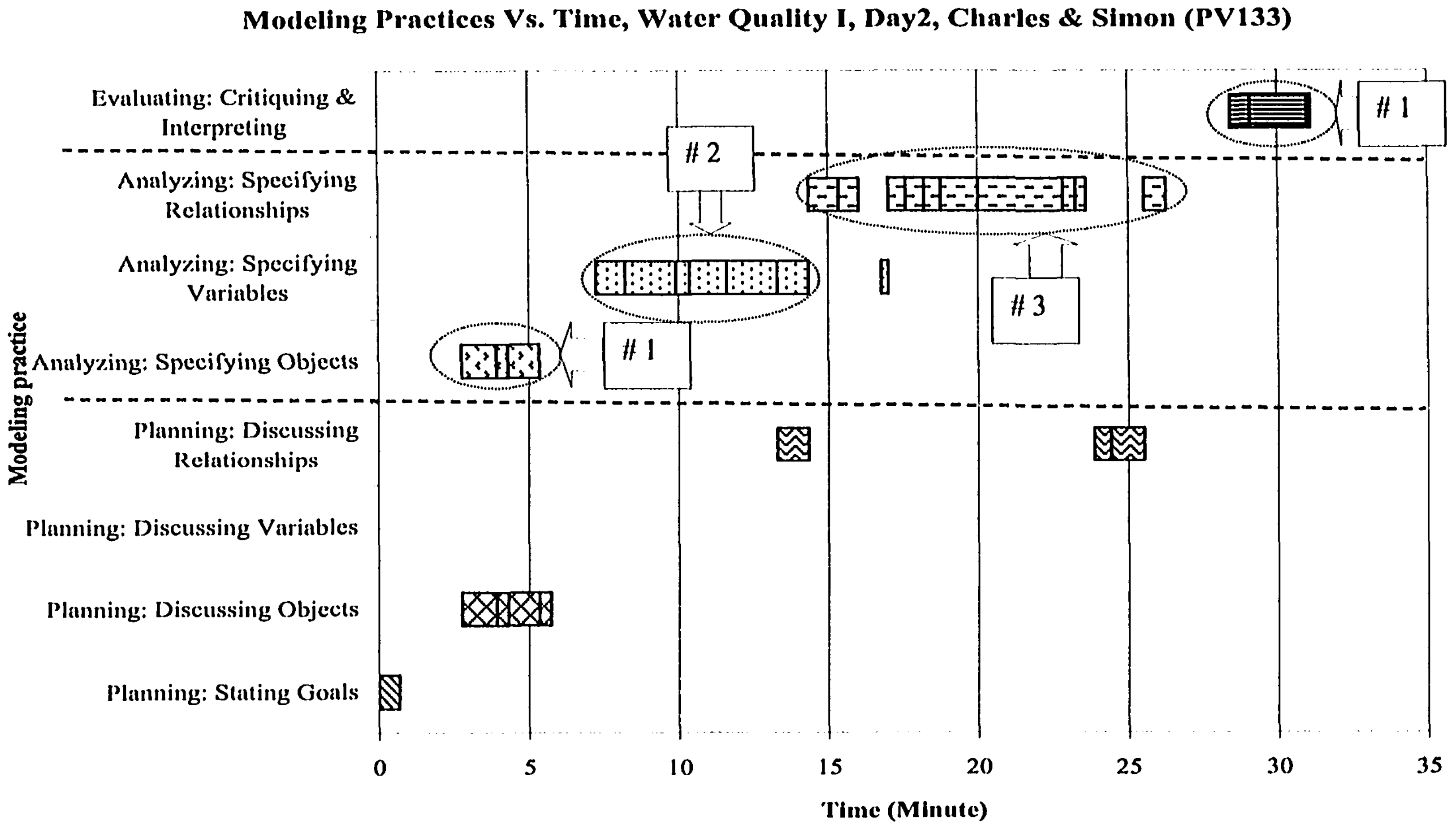


Figure 4.4. Modeling Practices (PV133, Charles and Simon)

In summary, the modeling program seems to facilitate student analyzing practice considerably because students learned to use it in one day and were able to create model objects and variables without much difficulty operating the software. This initial analyzing practice is a process of sense making with a process of getting familiar with the modeling program and the concepts of modeling. The meaningfulness of the practice seems to be influenced by student understanding of modeling, as shown in the case of Simon and Charles (PV133), and the way the modeling program works. Further, teachers have a big influence on how students perform the practice at this early stage.

Synthesizing Practice

Synthesizing practice reflects student modeling actions and conversation about putting different modeling components together in representing the driving question or focus of a model. In general, there seemed to be two ways that students demonstrated synthesizing practice. First, the test mode of Model-It was designed purposely to promote synthesizing practice. Synthesizing could happen when students popped up the meters and ran simulations to see how the change of one variable affected other variables that had relationships with it. Second, visualization of the model layout in build and test mode with all the variables and relationships could help students think about the model as a whole. Therefore, it helped students to plan what kind of model to create, rearrange the model layout to highlight more important variables and relationships, and discover anomalies, such as an incorrect association between a variable and an object.

For the first way to promote synthesizing practice, there were cases showing that the test mode worked the way the designers expected. All six pairs demonstrated synthesizing practice when using test mode. The following excerpt shows a typical example of how testing allowed students to synthesize their ideas of a model (PV 142, Charles and Simon). This example also shows that synthesizing and testing helped students to discover an anomaly that was different from the student expectation [Line 16]. However, Charles could not propose a solution that might lead to the improvement of the model.

----------TEST

1 (PV142) 0645 Open all the five meters.
2 The meters overlap.
3 Charles: wait, wait, we have to be able to see 'em.
4 Rearrange meters to see all of them.
5 Play simulation.
6 They adjust the independent variables.
7 Charles: Why is this (meter) yellow?
8 Charles: Water quality is very good if there is medium people.
9 Because there's not many animals, whoa!
10 What do you think, watch conductivity, it's getting lower,
11 it's getting lower, it's getting lower, it's medium.
12 At what point does it change here?
13 Simon: When there's less people then the conductivity is a lot
14 Charles: There we go, we should have medium people, that way... everyone's happy.
15 See they (all the other four variables) are all dependent on the amount of people.
16 Simon: ...So why is the water quality going up when there's a lot of people?
17 Charles: Because there's less animal waste,
18 because the people that hunt are more.

For the second way of promote synthesizing, the visualization of available objects, variables, and relationships in plan and build mode became necessary. The use of visualization of the model layout for synthesizing happened in varying degrees across the six pairs. The example below shows how Nathan and Kelly created relationships using the available variables they had planned (PV140, Lines 1-5).

1 (PV140) 2833 Nathan moves his cursor around the variables
2 and tries to make the next connection.
3 Kelly says it seems they have done the # of trees
4 and the # of leaves, but
5 Nathan says that's the size of trees.

New relationship: As TREE-the # of trees increases
TREE-the # of leaves increases a lot BECAUSE...
[Ss seem to have some variables that are similar].
Nathan agrees with Kelly that the tree leaves like
multiplied when # of trees increases.

Synthesizing seemed to be a difficult process because students had to reorganize the concepts and make logical connections among them. The result of the practice might be a model like that of Nathan and Kelly with a very sophisticated web of relationships (Figure 4.5) or a parsimonious one like Abby and Don's final model that took them only 18 minutes (Figure 4.3). Kelly and Nathan's model became more and more complex when they had done a relatively thorough analysis of their major variables, especially of the object TREES. They had four variables for the object: *the number of trees, the size of trees, the number of leaves,* and *the location of trees* that might contribute to the effect of trees on STREAM water quality, such as turbidity. Students had five water quality tests during their investigations: turbidity, pH, temperature, conductivity, and DO, and they put all the variables in the model as well. They also had another object, PARKING LOTS. Therefore, when they detailed the causes and effects of the water quality system, everything seemed to be inter-connected. They finally developed a concept-web like model to describe the phenomenon.

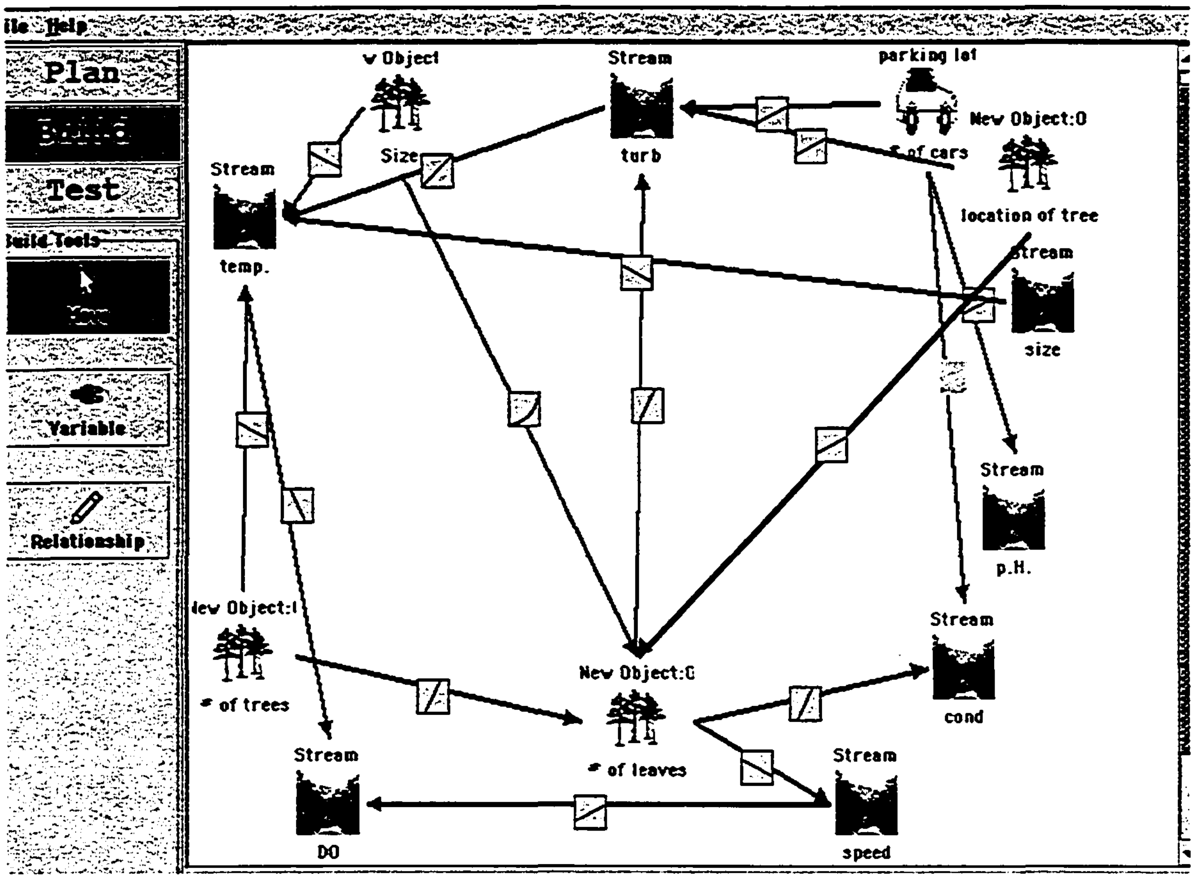


Figure 4.5 Kelly and Nathan's Final Model of WQI

Abby and Don, on the other hand, used all six objects on the image palette and created nine objects and at least one variable for each of the objects. The objects were all relevant to water quality because the teachers had selected them and emphasized objects and variables in their curriculum (Figure 4.3). Since the students did not have a shared focus, they finally found that they could not articulate the model to others. However, after about four days of struggling to make sense of the variables and relationships, a focus and the relevant objects, variables, and relationships seemed to emerge and Abby decided to create a new model. This time she had focused on how things affected water quality DO. The model she created seemed to make more sense to her and her partner. The model was parsimonious because it only had 6 objects (PLANTS, WATER FLOW,

PRECIPITATION, ANIMALS, PLANTS, TEMERATURE), 6 variables and 6 relationships but accurately described how things affected DO (Figure 4.3).

In summary, synthesizing practice occurs with the use of the test mode when running simulations to get the instant feedback on how independent variables affect dependent variables. Visualization of the model layout also promotes synthesizing. Synthesizing practice seems not to be effective in improving a model's quality unless there is an obvious focus. Synthesizing practice is effective, which means it produces accurate models, when students think through a phenomenon and understand it conceptually.

Evaluating Practice

Evaluating practice reflects student modeling actions and conversation about making judgment of the quality of a model using certain criteria. Test mode was designed to promote evaluating practice so students could see whether their model was functional based on the simulations. It was evident that testing could help students to discover anomalies, such as whether one variable affects other variables in unexpected ways. Students were motivated by the expected model behaviors. A typical example is in the following excerpt from Day 2 (PV134) for students Cathy and Shirley. The comment they made was that the model "works" [Line 10].

----------TEST
1 (PV134) 1918 Cathy: play.
2 But since they don't have meters, nothing happens.
3 Shirley: meters.
4 They open all meters. They change the values of meters.
5 Cathy: oh, what? [They don't see changes.]
6 Shirley: we need to put play.
7 Students try to make sense of their model.
8 They adjust the values.

9 Cathy: so we have more people, more thermal pollution, and low fish.
10 Shirley: we did it! It works.
11 Shirley: we better save.

On the other hand, unless students have really thought about their model conceptually and holistically, they might simply comment on whether they had seen how independent variables affected dependent variables in the way that they expected. There was a lack of conceptual judgement on what "works" or "not works" means. Most students tended to evaluate a model in terms of whether individually relationships "work" but not how the whole model answers the driving question and explains the whole phenomenon. Further, even if they find an anomaly, they might not be able to find the solution. The following excerpt shows that Simon missed at least the second occurance of an anomaly (PV151) [Lines 16-17].

-------------TEST
1 0950 Open all meters and click on play.
...
2 Simon: oh, we can't change it [conductivity] here.
3 People is like the main thing here.
4 Charles: 'cause it is independent.
5 Simon: everything depends on how people are.
6 Charles: if "people" is low here, there is high water quality.
7 Simon: yeah, look, if it is high, there is high hunting.
8 Charles: all we need is water quality, really, look,
9 if a lot of people, high to medium, water quality.
10 [Charles has seen the most important variable.]
11 He adjusts the value.
12 Simon: because people hunting.
13 Charles: Low people, really high quality.
14 He adjusts the value.
15 Charles: So it goes down to more people.
16 No, it goes up as well.
17 How do I get that to meaning?
18 (Because between people and conductivity there is a variable hunt,
19 changing people to either high or low value will increase conductivity.)
20 Simon laughs.
21 Charles: so more people water quality goes down slowly.
22 See, goes about from here to here.

23 So people negatively affect.
24 Simon: yes, negatively.
25 Charles: that answers our driving question.
26 Simon: how do people affect the...
27 Charles: no, wait, we also have factory stuff as a part of it.
28 Simon: it's really weird.

The real reason for the anomaly was that there were two threads of relationships affecting water quality but in opposite directions. Both threads started from the independent variable PEOPLE: *many people*. Thread one was that with more *many people*, more *people hunt* so that fewer *animals* and less *animal waste*, thus less conductivity and higher water quality. Thread two was that more *many people*, more *conductivity* so that lower *water quality*. Unless students highlighted one of the threads by making the *many people* impact bigger, the testing result would not make sense to them [Line 28]. Student difficulties could be due to their developmental stage in that they were not able to put all the available information together to debug the anomaly. Another possibility is that considering a model as a system has not occurred to them.

Teachers also knew that students needed help to evaluate their models. In class I, the teacher Alice provided a checklist for students to examine their own model. The major questions were: a) Does the model address our driving question? b) Do you need to remove objects or variables? and c) Do you need to change relationships? The checklist seemed to provide a direction for students to evaluate their models. For example, Charles did not have a driving question in mind until he read the first question on the checklist (PV142) [Lines 5-9]. The checklist required students to review their models in order to answer the questions [12-15].

-----------PLAN
1 (PV142) 0321 (according to the teacher's instruction, they should address some

2 questions first)
3 Charles reads through the questions on the board and makes sure that they
4 address each of those.
5 Charles: "Does it address our driving question?"
6 Read the board.
7 Simon: yeah.
8 Charles: what is our driving question?
9 Simon: how does the conductivity affect water?
...
---------TEST
10 0337 Charles: okay, yeah, we have addressed our driving questions.
11 Simon opens meters.
12 Charles: do we need to remove objects or variables?
13 Again, he reads the instruction on the board.
14 Simon: uh, let's see.
15 Switch to BUILD.

However, the evaluation could be superficial with constrain on understanding of modeling and content. Cathy and Shirley checked their model after the teacher reminded them and when they were stuck without knowing what to do [Lines 1-4]. They spent only one minute examining their model (PV143). Cathy made the conclusions instantly without asking Shirley [Lines 6-12] and she forgot their driving question [Lines 14-18], too. It was good that they referred to their notebook for their driving question [Lines 19-20]. It seemed that students were defending their position through the examination [Lines 21-23] instead of getting new ideas for improving their model.

----------BUILD
1 (PV143) 1526 Shirley: we can make another people.
2 But they don't carry out the suggestion.
3 They scroll the window up and down.
4 They are stuck and don't know what they can do next.
5 Cathy reads the instruction on the board step by step.
6 Cathy: "Decide if you need to add another object."
7 We don't need to.
8 "Do you need to change relationships?"
9 Yes, but we can't.
10 (They were not allowed to make an feedback loop.)
11 "Do you need to remove objects?"
12 No.

"Does the model address your driving question?"
What is our driving question?
Shirley: How does the thermal pollution affect how fish live?
Cathy: no, it's not.
Shirley: oh, great. [giggles]
Cathy: it would be like people.

1613 Shirley checks her notebook (according to the sound of flipping paper).
Cathy: How do people affect the level of thermal pollution?
Shirley: we have people how much they litter and how much they dump into the water. We have fish.
Cathy: it's done. We are done our model.

In summary, test mode initiates student evaluating practice. It also facilitates student evaluation of a model when students learned how to use the meters and graphs. Student evaluating practice seems to be constrained by their understanding of content and modeling. There seems to be a need to include explicit explanations in the software or the curricula showing what is considered a good model and whether a model has served its purpose.

Publicizing Practice

Publicizing practice includes student modeling actions and conversation of presenting a model to people other than their group member(s) and their class. Publicizing happened when students were asked to explain their model during their modeling process and when they needed to present their model to the class at the end of the modeling cycle. They were forced to think through their model in order to be able to present the model and make it understandable to others. Further, since students presented to a larger audience who shared similar experiences in this learning community (the class), they were able to receive comments and feedback from the teachers and peers at time when they are ready to learn.

The following excerpt (PV142) shows that publicizing forced students to elaborate their ideas [Lines 1-9]. The teacher's comments and feedback seemed to come at the right time because students seemed to be ready to accept and make sense of the teacher's suggestions [Lines 10-33].

(PV142) 1451 Teacher: so what are you guys modeling?
Simon / Charles: ...How conductivity affects OUR STREAM.
Teacher: so what do you have there?
Charles explains what they have.
Charles: How many people there are, and that affects how many people hunt,
and the people dump chemicals into OUR STREAM object
so that would raise conductivity.
And the people that hunt will lower the amount of animals
and the less animals there would be less conductivity in OUR STREAM.
Teacher: well, fewer animals are less conductivity and why is that?
Charles / Simon: because there are not much animal waste.
Teacher: in your model somewhere,
what is it in terms of chemicals or animal waste?
Did you write anything about dissolved substances?
Charles: no.
Simon: Uh, huh.
Teacher: what kind of chemicals have we specifically talked about?
Did you pull out your water quality booklets?
Charles / Simon: salt.
Teacher: okay, maybe salt.
So you need something in here about winter and salt.
What else in terms of conductivity?
Do you have your conductivity booklets?
What contributes...
What are the three main substances we were talking about?
Charles / Simon: oh, phosphate, nitrate and salt.
Teacher: okay, somewhere I should see that.
Animal waste is one.
Fertilizers or other organic waste.
We didn't talk about hunting in terms of our water quality.
So you may add something here and make some adjustments.
Make sure you have a comprehensive model of conductivity.
Question?

Since the teacher reminded the students to address an important object, salt, that impacted the local area very much during winter (PV 142, 1451, Lines 20-21), students actually were able to deepen their understanding by introducing a new object and variable [Time of the year]. As shown in the following excerpt (PV 142, 2535), salt was only used on roads in the winter; therefore, how to represent the impact of weather in winter became a challenge [Line 8]. The teacher proposed some ideas [Lines 14-20]. After talking to the teacher, Charles seemed to come up with an even more parsimonious way to express the idea [21-24].

1 (PV142) 2535 The teacher stops by.
2 Teacher: your object is weather, but your variable is weather.
3 Simon: I told you (Charles).
4 (Earlier Simon disagreed with Charles about having the same object and variable.)
5 Teacher: so we want number...
6 Charles: oh, so we should have like snow or something.
7 Teacher: I don't know. Tell me what you're trying to do.
8 Charles: we try to show the salt. Like people put salt in the winter.
9 Teacher: okay, so as weather as the amount of precipitation goes up,
10 or the amount of snowfall.
11 Okay, I see.
12 You want to show the weather affects the amount of salt.
13 Charles: Yeah.
14 Teacher: So I would say. You could have two (variables).
15 You could have temperature as warm, cold, right?
16 so your object will be weather, and your variable will be temperature. Right?
17 Charles: yes.
18 Teacher: ...and connect to another one that says weather and the amount of salt.
19 And put those two together. As the temperature goes up that...
20 So temperature you can have rain, snow or something.

21 2655 Charles: wait...I got it.
22 Charles modifies their variable name from weather to "time of year",
23 and change the scales to winter/fall/summer.
24 They keep the previous description.

Student pair Jackie and Elias spent the whole class period on Day 4 preparing for their presentation (PV155). During episode 0300, they split tasks according to the number of variables [Line 11]. During episode 0630, they decided to split the task according to the order of the arrangement of the variables and relationships on the model layout [Lines

22-23]. This might be consistent with the first agreement [Lines 4-7]. However, during episode 0901, the tasks were split conceptually which means the model became more meaningful to them [Lines 28-30].

---------TEST

1 (PV155) 0300 Jackie: So, let's start.
2 Students begin walking through model, variable by variable,
3 talking about how each one affects the next.
4 Jackie: we start like this, first one, if there is a lot sunshine,
5 Then plants will grow, then we go to the sunshine that if it is
6 Too hot, there is thermal pollution.
7 Elias: Go down…I'll say things about flowers and mean trees.
8 Elias: How many are there (variables)?
9 Jackie: …five, six, seven, do you want to do four or three?
10 Elias: I don't care.
11 Jackie: I will do these four, and you will do these three, OK?
12 (Students are apparently preparing for presenting their model.)
13 Elias: now we have to pick up an order.
14 Jackie suggest that she starts with the two variables of SUNSHINE,
15 Then Elias explains the three variables he promised.
16 The last one is the water quality because (it's the effect).
....
17 0630 Call up meters
18 Run test
19 Manipulate independent variable.
20 Elias: The only thing we could improve is water quality.
21 Jackie: Why don't we explain that.
22 I say how the bright sunshine affects everything else.
23 And you say how these affect these. OK?
24 Elias: OK.
...
25 0901 Ss continue to step through each relationship,
26 Elias: I want to start the independent variable from "medium"
27 He then looks at the changes of other variables.
28 Jackie: How about I explain the independent variable
29 and you explain the rest of the variable?
30 Elias: OK.

Further, within student groups, publicizing also promoted synthesizing and group collaboration. Charles and Simon also modified their driving question (PV151, 2111, Lines 14-15) to be more accurate in representing the ideas in their model. This shows that the need for presenting and publicizing promoted synthesizing so that their driving question was also better aligned with the model.

(PV151) 2111 Students prepare for their presentation.
Charles: we have to write our scripts [for presentation].
Simon: so how do people and animals affect conductivity
that was our driving question?
Charles: well, we will say, see...(Pause).
Simon: what are you doing now?
Charles: we have to write our scripts.
Charles: wait, how...
He's writing their scripts.
Simon: do we need to write a paragraph? What should we do?
(They are quiet for seconds.)
Charles: okay, our driving question will be how do people
affect conductivity of the OUR STREAM.
Simon: I think we have animals in the question.
Charles: okay, people and animals.
Simon: (driving question) how do people and animals
affect the conductivity of the OUR STREAM.

On Day 3, Shaw was almost excluded from the modeling process because Lisa started a new model all by herself. Lisa seemed not to be productive. On Day 4, they were able to work together and discuss decisions with each other although there were still some glitches, such as one person not listening to another. The attitude change for Lisa was probably due to the need for presentation (PV154, 2530, Line 2]. Otherwise, she might not have even talked to Shaw as on Day 3.

(PV154) 2530 Lisa: what do we say.
We have to decide what we are going to say.
Shaw: We need to watch it.

In general, publicizing forces students to articulate and elaborate their ideas. The need for publicizing also requires students to collaborate in order to have shared understanding in order to present as a group. It is certainly beneficial to students when they receive just-in-time input for moving them forward as the above example of teacher intervention shows. It is also reasonable to predict that students might be able to become more purposeful in their modeling process if there is a need for publicizing.

Other Dimensions of Student Learning Involved in Their Modeling Practices

As mentioned in Chapter 3, the methodology of this study is aligned with the approach of "design-based research". Since some dimensions of learning other than modeling practices were also identified during our first enactment of the curricula, the following sections address those dimensions that were identified. They are student metacognition, inquiry experience, content knowledge, modeling knowledge, and collaboration.

Metacognition

Metacognition seemed to be demonstrated through the following aspects of modeling actions and practices. First, reflecting and monitoring practice showed student awareness of their progress. Second, seeking information and help when needed also showed good metacognition. Third, students who used their notebooks, investigation booklets, and other resources might have better metacognition because they used the above strategies to move forward during their learning process.

Implicitly or explicitly, students were aware of their progress. For example, students "save" their model frequently without their teachers' reminders. Charles and Don even developed a habit of reading the time counter on the data recording equipment to monitor their progress. On the other hand, following teachers' instructions provided a common strategy for students to check their progress. The most significant example was Simon. He followed the teacher's instruction closely. For example, they were ready to test their model at the beginning of Day 3, but Simon changed his mind and went back to plan mode because the teacher provided a checklist for them to examine their model (PV142, 0321).

Visualization of the model layout seemed to help students to reflect and monitor their progress. Nathan frequently paused and rearranged the model layout for new ideas for building or modifying their model. In fact, almost all students made use of the model layout to help them plan, analyze and/or synthesize, and reflect on their model and monitor their progress.

Besides reading the timer on the recording machine frequently to monitor their progress, like Charles and Don did, most students learned to use the visualization of the model layout to reflect and monitor what they had created and decide what to do next. However, only Charles and Simon and Cathy and Shirley rearranged the model layout to purposefully highlight the more important variable(s) or group the variables of causes and effects. For Cathy and Shirley's model (Figure 4.6), the STREAM: thermal pollution variable is in the middle of the model layout; all the (four) variables that affect thermal pollution were put on the upper part of the screen. All the (four) variables that were affected by thermal pollution were put on the lower part of the screen.

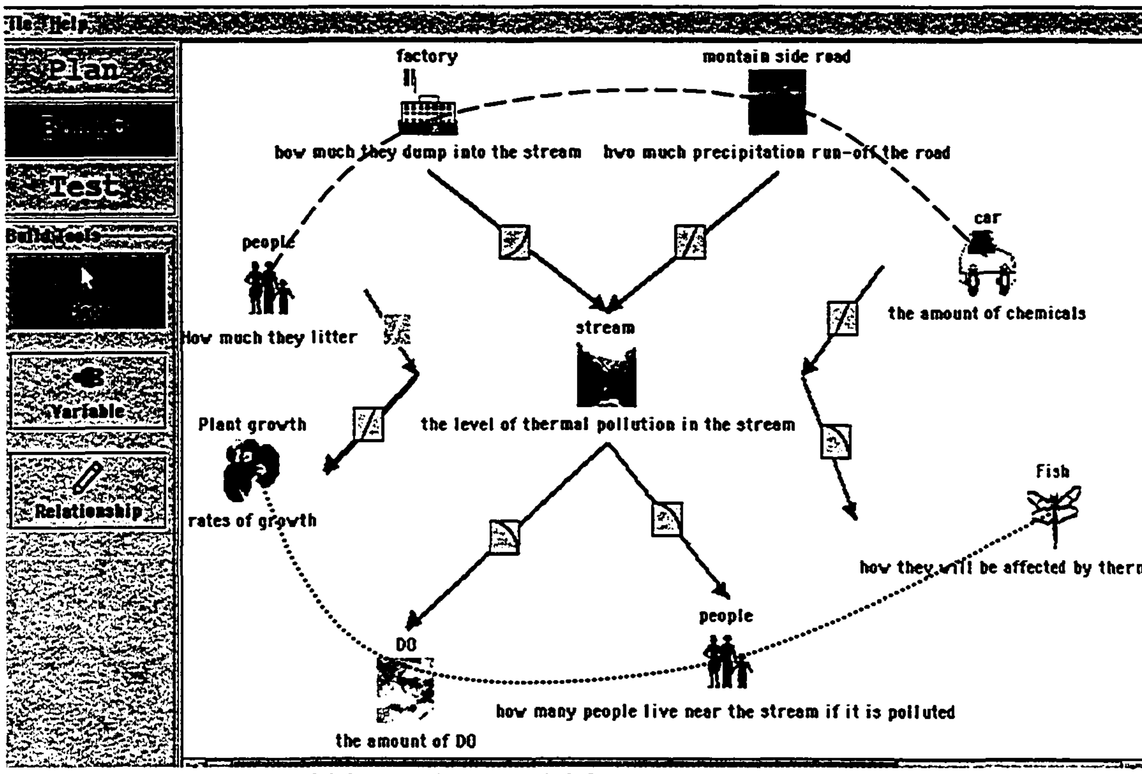


Figure 4.6. Cathy and Shirley's Final Model from WQI

Not all students had the good habit of asking questions to the teachers, researchers, or peers. This could be very frustrating for some students when they were stuck. For example, on Day 2 (PV139), Abby and Don did not understand what a variable was [Lines 4-17]. They struggled and even created some relationships, but they did not ask until the next day (PV148, 0858).

1 (PV148) 0400 Abby: let's do variables.
2 Students pop up the variable editor,
3 choose object "cloud" from the drop down menu.
4 Abby: ok, what are you there?
5 Don: type in the variable name.
6 Abby: (anxiously) what is a variable? I do not understand!
7 Don: see what we did for human…
8 Abby: what is a variable? I am really confused.
9 Don: Ah, how many clouds we have.
10 Variable: how many clouds we have.
11 Students choose "number" for initial value
12 (They might not understand why they give a value there).
13 Don tries to change the default initial value.
14 Abby: there is a high amount of cloud, description!

15 Description: many clouds.
16 Abby: do you know if this is what we are supposed to doing?
17 Don: I have no clue!
18 Abby: OK.

The same issue also affected student pair Lisa and Shaw. Shaw was more open and was not shy about asking questions. However, he was excluded from the decision making and modeling process when Lisa felt that he was dictatorial and disrespectful to her ideas (PV136). Lisa never asked a question of anyone except Shaw, although she had questions from the very beginning. For example, she had to delete two objects because she did not know how to find and delete the variables that were attached to them (PV136).

Using resources seemed to help students deepen their understanding. For example, on Day 4 (PV152), Shirley articulated the relationships around thermal pollution and they finally decided to add STREAM: DO to their model, which was about thermal pollution [Lines 2-12].

--------TEST
1 0435 Open all meters and rearrange them.
2 Shirley: thermal pollution is like not in here [the science book].
3 Cathy: good.
4 Cathy to the class: did thermal pollution affect...okay...
5 [Cathy wants to ask this question to the class, but she then gives up.]
6 Shirley: oh, thermal pollution will be ending up like temperature.
7 [She finds something about thermal pollution on the book.]
8 Shirley: here we go. Wait, cold water holds more oxygen than
9 warm water, so there is less DO, if there is thermal pollution.
10 Cathy: no...what this means is that the water is warmer...
11 Shirley: no, 'cause thermal pollution is temperature.
12 Cathy: oh, so less DO.
13 Shirley: Just add that up.

In summary, metacognition seems to be an important part of student modeling process to make the modeling process productive and more meaningful. The good habits of seeking information, asking for help, and using resources seem to be helpful for students to receive more input in order to move forward and make sense of their modeling practices.

Content Knowledge

Content knowledge was certainly important for students to be able to create a model. As teacher Alice pointed out in her first class in modeling, Model-It allowed users to create objects, variables, and cause and effect relationships, but users had to decide on the content of the model. The purpose of creating a model was to represent student understanding of water quality. The first time, the teacher only asked students to create a simple model. Their driving question had to be based on one of the five water quality tests (CV126). When the teachers introduced the concepts of modeling and the use of Model-It, they also emphasized the content knowledge students had learned when proposing objects, variables, and relationships. For example, the range of conductivity should be from 0-50, pH values could go from 0-14, and water quality had four measures: Fair, poor, good, or excellent but students were only able to choose three options because of the variable editor of the program only allowed three options (CV132).

The process videos only allowed me to capture what students had talked about but not what they had actually typed. Further, the teachers only asked students to create a simple model and suggested them to use only one of the five water quality tests as their foci. Therefore, it was difficult to capture the whole picture of student understanding of content. The following instances might show that modeling knowledge did impact student modeling practices. Lisa and Shaw were the only pair that did not have a high achiever among the six target student groups according to the teachers' records (Table

3.3). They were the group that was not quite productive and did not collaborate well because both of them did not have many ideas about building the model. In another pair, Elias was a low achiever, therefore, Jackie proposed most of the ideas and she used her mouse to direct Elias to do what she wanted to do. The PVs showed that both student pairs had difficulties understanding concepts related to modeling as well. It seems that the lack of content knowledge in addition to the new concepts of modeling exacerbate the difficulties of those students.

<u>Inquiry Experience</u>

There were only a few instances in which students used their investigation experience to support their arguments. When filling the description of a HUMAN object, Abby told Don that "I do not remember what we do for human." Don did not remember either. The following episode shows that Abby and Don used their investigation data to decide the initial value of their variable: the amount of plants (PV139, 0623).

(PV139) 0623 Don clicks on the new variable button to do new variable.
New variable: plants-the amount of plants.
They then agree to set initial value as high.
Abby: Description? a lot of plant, a lot of ...areas
Don: oh, yeah, yeah, yeah!
How many plants are there in our sections?
Abby: B, there is a lot, and D there is a lot.
Don types in "medium amount."

The use of investigation experience also helped Nathan and Kelly when they decided the initial value of the variable: conductivity. The following excerpt illustrates the case (PV140, 2141). However, this was the only instance in which students referred their investigation experience.

-------------Plan mode
(PV140) 2141 Nathan: and then conductivity.

New variable: STREAM conductivity, text,
Initial value: high, no description.
Kelly: we had high conductivity, very high, didn't we?
Nathan puts the initial value as high.

In general, there seems to be a lack of connection between what students presented and what they had captured from their data and data analysis. One reason might be that students were very familiar with issues of water quality, so they could easily create a general model of water quality without having to refer to their investigation for specific details. It is also difficult to capture the instances when students used their investigation experiences to make decisions on what to build in their models because they might not have spoken what they were thinking. The modeling pairs are also the pairs who did the investigation together according to the teachers' arrangement. Since the process videos and classroom videos were not able to capture what students talked about during lunches, at working sessions, or in other situations as part of their planning process, their thinking remained tacit to researchers.

Modeling Knowledge

Modeling knowledge was mostly captured with student conversation. It included student understanding of the purposes of models and modeling, objects, variables, relationships, and the evaluation of a model. Don explicitly claimed that he did not know what they were doing (PV 130, 0513). There seemed to be no opportunity for students to demonstrate whether they understood the purposes of modeling. Although teachers told students that modeling was to show their understanding of water quality (e.g. CV132), there was no further explanation of the reasons for doing modeling.

For similar reasons, students did not know what counted as a valid variable name and how to fill in the descriptions of objects, variables, and the "because statement" for the relationships. Most students had similar experiences to Charles and Simon. The following example (PV133) shows how Charles and Simon name their first variable [Lines 1-5] and fill in the description of the variable on Day 2 [Lines 6-11].

(PV133) 1022 Charles: How do I get a variable to this (the ANIMAL object)?
[This is a utility problem. On the opened variable editor, they don't know how to create a variable for a specific object they want.]
Then they realize they can change the object on the variable editor.
They set the object as ANIMALS.
Simon: what am I supposed to write?
[He doesn't know how they should name the new variable.]
Charles: this is animals (giggles).
Charles: animal waste affects the conductivity.
They name the variable as animal waste, text, high/medium/low, medium.
(Their DQ should be something about conductivity.)
New variable: ANIMAL-animal waste, text, initial value: default (medium)
Description: the animal waste affects the conductivity of the OUR STREAM.

Charles and Simon started creating variables after they finished creating objects. They first figured out how to locate the object they wanted a variable to associate to by trial and error (PV133, 1022) [Lines 1-5]; then Simon did not know what description he needed to write. Charles first proposed a name identical to the image that they had chosen. He seemed to know that it did not make much sense and he giggled (Lines 6-8). However, when he elaborated on why they had the ANIMAL object, it was clear that they needed a variable of animal waste and they also figured out what they needed for the description of this new variable [Lines 9-13].

Although students need to learn modeling knowledge through their modeling practices, it might be better to emphasize the basic concepts of modeling, such as what a variable is, and how to provide descriptions to a variable or a relationship. Student understanding of the modeling program also influences how students make use of the modeling experience. The following excerpt was on Day 1 (PV130, 0513) for student pair Abby and Don. They did not know how the program was structured. They remembered how their teacher assigned a variable, but they did not know which box was for a variable's name [Lines 18-21]. They had no sense about what a model looks like because the teacher only showed them how to create objects and variables. They only had one object and one variable so far [Lines 27-28].

(PV130) 0513 Abby: Now let's do variables.
How many variables?
Don: you want a "text or number?"
[Don is not answering Abby's question but talking about Abby's
selection on the variable editor.
It seems he has no idea of Abby's question.]
Abby: I do not know.
Don: let's do number… or use text range
Abby clicks on "high" button and pops the window that
she can change the text value.
Abby tries to type in something and surprised to realize
Abby: the value, number?
Don: oh, how many human is around?
Abby: She (the teacher) did like "how much" or "how many"
(Students did not fill in the variable name box so that they
did not know what they could do with the initial text value box.
Then they leave the textual value as "default" and go to the "description box")
Abby: how to do that?
Don: I have no clue about what we are doing!
Abby types in something that can not be see clearly and dismisses the
variable description box.
Variable: HUMAN-default name (no name), text, initial value: default.
Description: could not been seen
Abby was surprised when accidentally put her cursor on the variable icon,
She sees the number of variable to be "one" and the description.
Abby: look, cool.
Don: I still do not see our model.
Abby: look (pointing to the human icon), that is our model.

It was not surprising for them to have such difficulty. As the following excerpt shows, they even did not know how to name a variable (PV133) [Lines 2-7].

(PV133) 2100 Don pops up the variable editor.
Don: what should we put here (as the variable name).
New variable for HOUSE object.
Don says that the image looks like a condo,
So they put "3" as the variable name.
Initial value: (Number) about 3.
Description: (Cannot be seen.)

Teachers showed students how to create a model including naming objects and variables, and filling descriptions and because statements. However, making sense of the concepts and rationale of modeling seems to take time. The scaffolds, such as the object and variable editors, and the relationship editor allowed students to create objects, variables, and relationships, but the scaffolds were not obvious about how to do it and do it right. Also, computer-based modeling was new to the teachers themselves. There needed to be a study like this dissertation that helped the teachers to discover student difficulties and provide strategies for teaching with Model-It and general modeling.

Collaboration

There were three ways that I looked at student collaboration based on the literature and initial enactment of the curricula. First, whether all students in a group were engaged, which means that they were on task. Second, whether they had good rapport. For example, how students talked to each other, including the manner of their conversation and language used? Third, how students split the tasks? One interesting phenomenon was how students shared their tasks of being a mouser and/or a typer. In other words, who controlled mouse or keyboard?

Collaboration was shown from the various excerpts that were cited above in the results section. There was also a specific code called "off-task" that was used to code this type of modeling action. There were only five instances of "off-task" that were captured across twenty one class periods, the longest of which was less than one minute. This occurred with students Lisa and Shaw on their last day (PV154, 2245). The off-task episode happened before Lisa asked Shaw about how to prepare for their presentation.

For the following pairs, both students in the groups contributed to the model and had good rapport. Charles and Simon called each other nicknames. Charles calls Simon "Einstein" and Simon called Charles "Ford". Cathy and Shirley often completed each other's sentences. Kelly and Nathan talked to each other in the most respectful way. The following excerpt shows the manner of their collaboration (PV140).

For almost the whole class session, Nathan typed and Kelly held the mouse, but they worked like one person.

(PV140) 0556...
Nathan: you can do the mouse right now...
And if you want to type you can just tell me.

The following excerpt shows how they talked to each other in a respectful and responsive manner (PV140).

(PV140) 1507 Kelly: Ok, what are we going to do? Build?
Nathan: we probably should have one more object, shouldn't we?
Kelly agrees.
Nathan: do we have any more?
Kelly: we did not put like people, they can cut down trees,
I mean not only by our stream...might pollute.
Should I put people?
Nathan: I do not know. Let see "car".

Another type of collaboration was that one student took the lead and tried to engage the other one in the collaborative work. Jackie usually took the lead in her group. She directed Elias to do what she wanted by pointing and clicking on the modeling screen as a mouser.

The leader the other pair Abby and Don actually emerged from the modeling process. Both students had weak modeling knowledge and they did not ask their questions until Day 3. Abby gradually took the lead because Don became less responsible. Don's favorite phrases were "I do not know" and "why not". On Day 4 (PV157), Abby lost track of their model because they had 9 objects in a complex structure but they did not have a shared focus of the model (Figure 4.2). Then Abby started to work on a new model all by herself with the permission of the teacher and the agreement of her partner. She asked for Don's feedback for any decision she wanted to make. Since they had to work very fast, Don might not have been able to respond to all of Abby's requests. Don was not as engaged as Abby was. He was involved in some irrelevant activities such as talking to other classmates. Abby thus reminded him to collaborate [Line 8].

1 (PV157) 3105 Abby: then DO affects?...new variable.
2 Abby: New variable: ANIMALS-the amount of animals in water,
3 Should we do that?
4 Don: sure.
5 Abby chooses "text" and uses the default initial value on the variable editor.
6 Abby: description?
7 Don does not respond.
8 Abby: Listen, buddy, you have tell...
9 (Abby means they are sharing the work).
10 Don says sure.
11 After being silent for a while again, Abby types in the description.
12 Don: is that what we want?
13 Abby: Is that (the description) OK?
14 Don does not respond.

Among the pairs, Lisa and Shaw seemed not to collaborate very well. They basically tried to dictate the other what they should do without providing good reasons for his/her decisions, and they did not listen to each other. They were also the only pair that had a problem with sharing the role of being a mouser or typer. Shaw wanted to control the mouse so that they would do things they way he wanted. The same thing had also happened to Lisa. It happened again, as shown in the following excerpt [Line 1] form Day 3 (PV145). After Shaw was asked and was not being able to say what their driving question was, Lisa took the initiative and told Shaw her driving question [Line 5]. Shaw seemed not to pay attention to Lisa and asked again so Lisa told him a second time [Lines 6-7]. However, Shaw did not respond to Lisa [Lines 8-12].

-------PLAN
(PV145) 1115 Shaw: give me your mouse.
Lisa: give me your question.
Students start to create object.
Shaw searches for images without talking to Lisa.
Lisa: My question was how houses affect the water quality.
Shaw: how what?
Lisa: how houses affect water quality.
Shaw: what are you doing?
Shaw: let me see the mouse, we need a stream.
Students cannot find the icon palette,
and look repeatedly through the image folders.
Shaw: We are STILL not accomplishing anything.

Since Shaw did not confirm Lisa's driving question as their group's driving question, Lisa recreated a model all by herself (PV145, 1530). Lisa did not talk or respond to Shaw's suggestions. She did not talk to the teacher or other classmates either. The following example shows that Lisa had excluded Shaw from the modeling process [Lines 2-3].

-------TEST
(PV145) 2350 Open three meters
Shaw: I want to go see what others are doing.
Shaw: You are doing all the work anyway.
Lisa runs test.
Stop test, move independent variables.
Lisa runs test again (still no talking).

Lisa did not ask anybody or check for resources, she did not talk and had a difficult time deciding what to build in the model. Her difficulties might also have been due to learning of the modeling program. She had frequent short moves between plan and build mode as shown in Figure 4.7 (#1). The other actions included quick shifts between modes (two times, #2). She only created two relationships but tested the model three times (#3) and saved it two times (#4) during a 15 minutes period after she had worked all by herself since 1503 (PV145). There was no sign of planning when she started all over again. It seemed that she was not as productive as Abby and Don on their Day 4. They created a model in 18 minutes that was totally functional (Figure 4.3). Therefore, planning seems to be necessary and critical for efficient model building.

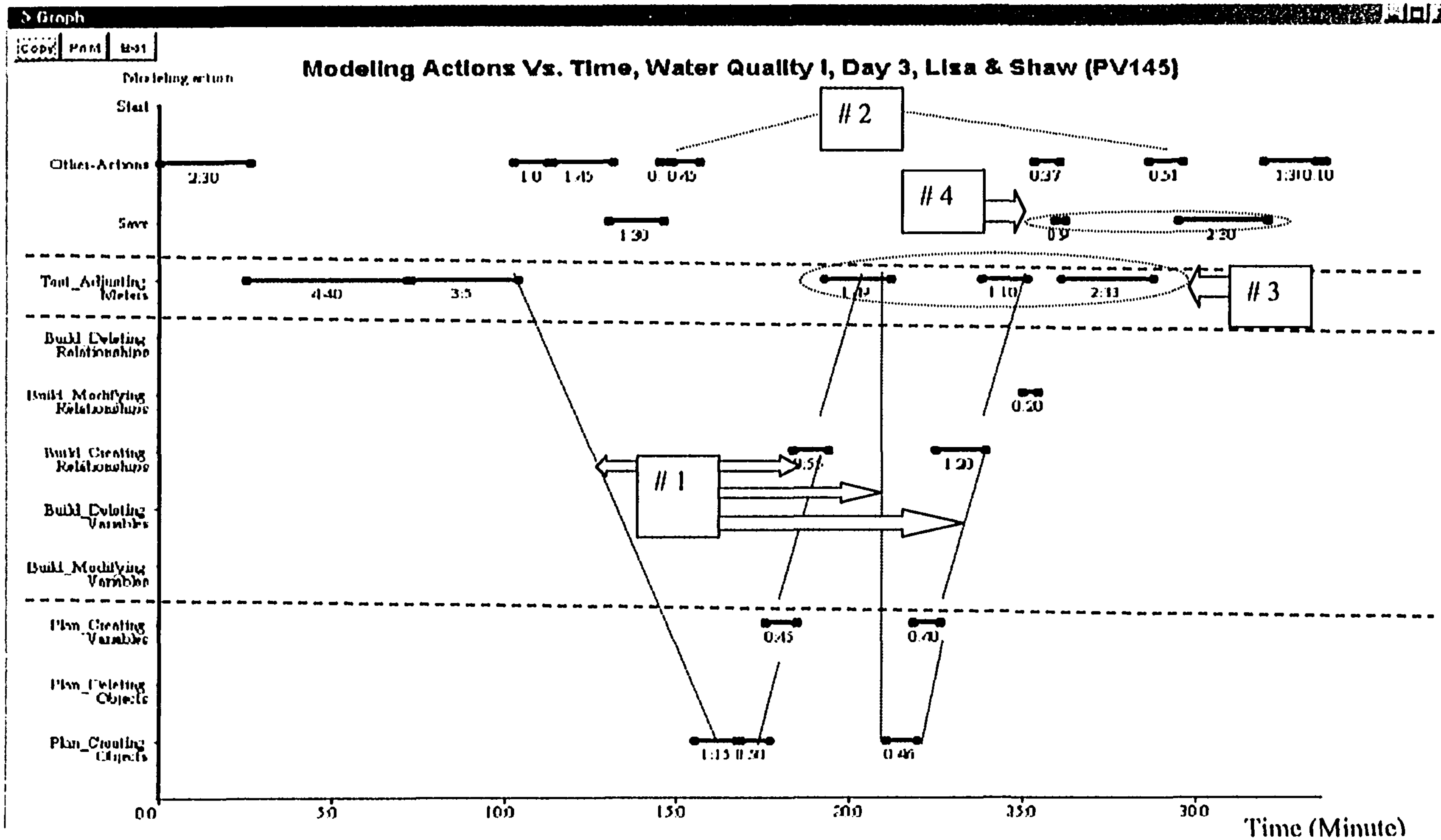


Figure 4.7. Event Recorder Chart: Modeling Actions (PV145, Lisa and Shaw)

In summary, different styles of collaboration directly impact the productivity of the modeling processes. Good communication allows students to fully understand each other and receive constructive feedback and, thus, improves the meaningfulness of modeling practices and the quality of models.

Student Modeling Practices during WQII

Using the same guiding questions that were illustrated in Table 3.13 and the same techniques to analyze the data, I looked at the same modeling practices and other dimensions of student learning in WQII and the decomposition unit. In this way, I was able to look at the changes in student modeling practices over time.

Planning Practice

Planning practice reflects student conversation about what they wanted to build in a model either at the very beginning of a modeling cycle or before they initiated a modeling action. In the second water quality modeling cycle, planning seemed to be more obvious, with more discussions on objects, variables, or relationships, for those pairs that collaborated well. Usually there were one or several episodes in which students deliberately planned their model during the first class period. Most students mentioned their driving questions at the beginning of this model cycle. They also questioned the alignment between the driving question and the model components they had built when discussing objects, variables, or relationships. They also sought images purposefully instead of letting the images lead them.

Most students seemed to plan purposefully when they started their modeling cycle in WQII, either together or separately. Three pairs of students mentioned their driving questions at the very beginning of the first class period. Cathy and Simon clarified their driving questions on Day 2. Although Jackie and Elias did not mention their driving question during the whole modeling cycle, they seemed to have a plan because Jackie asked Elias whether they had a variable for the SUN (object) on Day 1 (PV164, 1645). This also showed that they planned their model together. There was not a driving question mentioned for Nathan's group because his partner Kelly was absent for the whole WQII modeling cycle. Nathan took advantage of a screenshot of their model of WQI so that he basically was following the old model. As he mentioned in his class presentation, their model showed almost everything affected water quality (CV102). The following excerpt shows how he planned his model. He thought he was lucky that he and his partner had a screenshot of their old model (PV167, 0150, Lines 4-5).

--------Plan mode
(PV167) 0150 Nathan leaves the "unit" option as "none".
Therefore, there is no picture palette on the screen.
Nathan (it seems that he is talking to another boy):
I and Kelly are lucky because we saved a picture of our old model.
He then opens the model.
Nathan seems to show another student their picture of the model.

In a later episode, Nathan told the teacher that he was referring to their old model and the teacher did not have any comment (PV167, 0912). Their model in WQI was comprehensive including the five water quality tests. Besides copying things from their old model, Nathan also expanded it, which explains why their model of WQII was also very complex.

For students who had a plan or mentioned their driving questions, their constructing of models was more purposeful. For example, they selected images more purposefully. When creating variables on Day 2, Charles questioned why they had

PLANTS AND ANIMALS (PV169, 0313, Line 5). This also led to the clarification of their driving question (Lines 6-7).

---------Plan mode
1 (PV169) 0313 Charles: next variable.
2 Students search the objects they have.
3 Simon: let's do plants and animals.
4 New variable: amount of plants/animals.
5 Charles: why did we do plants and animals?
6 Charles: What's our question?
7 Simon: what are the effects and causes of thermal pollution?
8 Charles: why do plants and animals matter?
9 Simon: plants you mean?
10 Charles: plants and animals.
11 Simon: plants and animals? That's the effect.
12 Charles: okay. Okay....

It was interesting that Charles proposed the object PLANTS AND ANIMALS and suggested using the lily pad image on Day 1 (PV160, 0338) and now he was questioning it. Since Simon was typing and Charles was reading their notes for their plan, Charles might not have thought through the whole model. However, according to his answer to Charles' question, Simon seemed to know the answer to Charles' question (PV169, Lines 8-12). Simon's answer also shows that he was aware of the alignment of their driving question and the content of their model. This example further shows that it was very important for students to talk and exchange ideas and, thus, learn from each other.

Lisa and Shaw seemed to plan their model separately although they had a shared driving question, as shown in the following excerpt (PV164, 0120, Lines 3-4).

--------- PLAN
1 (PV164) 0210 (There is a lot of class noise, and the pair does not
2 vocalize much, often with just short, hard to hear comments.)
3 Lisa: our question is how do houses affect stream.
4 Shaw: right...there, we need a stream.
5 Lisa types in the description.
6 Create Object: STREAM, icon from image palette, normal, has description.

Abby and Don struggled with making sense of what they were doing, how to name a variable and fill in the description and the related conceptual issues with modeling. However, they were also more purposeful than they were in WQI. Abby first mentioned that they needed a driving question (PV 166, 0000, Line 7). She again proposed a driving question (Line 16). Don did not have more ideas so he agreed to use Abby's driving question (Lines 18-20). They then further articulated their plan for the model.

---------Plan mode
(PV166) 0000 Student names are on a sticker note on the computer screen.
Students laughed and Abby says "last time we do not know how to do this,
what we are going to do?"
Don: open it up.
Abby: where is it?
Then teacher reminds them that they are supposed to use Model-It 3.0.
...
Abby (seems not to let others know, whisper): what is our question?
(laughs) why couldn't we understand?
Don: sh...he does not want others to know either.
Abby jokes that this is just too hard for them.
Don: all right.
Our question last time was something like "turbidity".
Abby: that was bad.
We did not get it. (Laughs)
...
(Students have opened Model-It)
0141 Abby: Let's see if people can affect water quality,
Do you want to do that?
Don: That sounds a good idea.
Abby: does it?
Don: Is there anything else we can do? (Laughs)
Abby: how do people affect water quality?
Don: they build stuffs, we they build stuffs, they cut down the area.
Abby (then drags the image of a house) building.
All right? You can type.

For the only pair who did not mention their driving question, Jackie and Elias, seemed also to be purposeful in terms of the procedures of making a model. On Day 1, they created 9 objects in about 10 minutes. At 1030 (PV164), Jackie suggested "now let's do some variables." At 1419, Elias asked, "Do you want to try building it (build relationships)?" while Jackie kept suggesting and adding variables. They ended up with a model with 9 objects, 15 variables, and 26 relationships. But Jackie said that she was confused when testing the model (PV179, 1145 and 2210) even though she had decided most of the model components. It seemed that although they were purposeful on what they were supposed to do in order to create a model, they were not purposeful in creating a model with a focus. The following episode shows that they only had a general idea that CARS affect water quality (PV164, 1530, Lines 1-5) but had not thought specifically in terms of what their driving question was. Therefore, the model became less meaningful when they tested the model and tried to make a coherent explanation.

-----------Plan mode
(PV164) 1530 Elias: Should we make a car's variable,
for pollution and everything?
Create Object: CARS, has Description, Custom icon.
Jackie is thinking about description.
Elias: Air and water get polluted by pollutants from cars.
Description: (long but cannot see).

Figure 4.8 (PV173) shows an efficient modeling process of Jackie and Elias because they created 8 relationships in about 10 minutes (#1). It was somewhat purposeful, but not very meaningful in terms of thinking about a model as a system. Students Jackie and Elias seemed to think about each individual relationship with good reasons. However, they did not mention how the model as a whole represents a phenomenon. Part of the reason might be that they did not put their driving question upfront. Actually even when they were asked on Day 3, they were not able to tell their driving question. This can also explain why Jackie got confused and was not able to interpret the whole model when testing.

In summary, students seem to be more aware of the importance of planning than they were in WQI. In general, students are more purposeful in planning their model. They use driving questions as a way to organizing their ideas. Jackie and Elias was an exception for not mentioning their driving question, their planning process further shows the importance of planning with a focus.

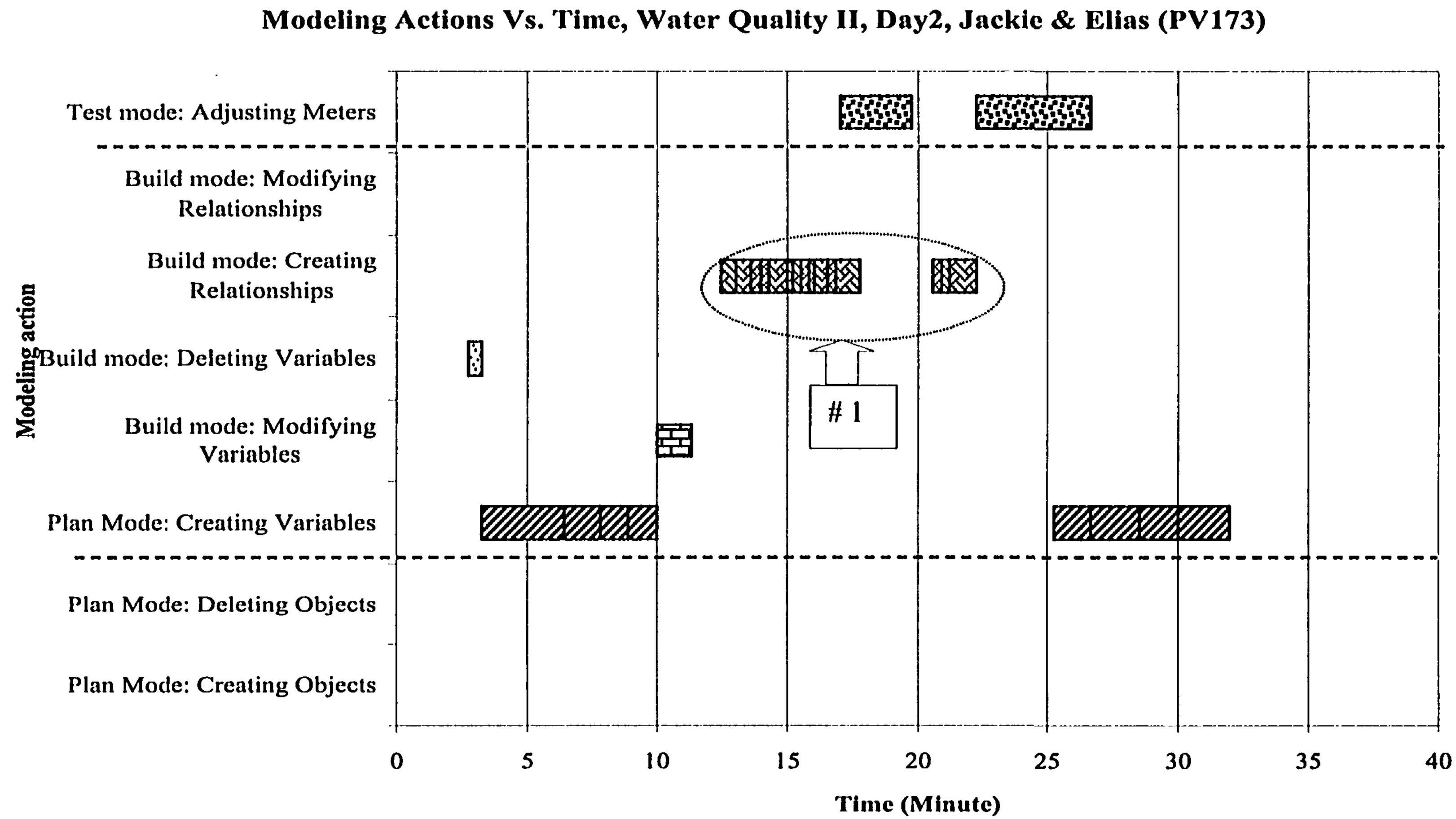


Figure 4.8. Modeling Actions (PV173, Jackie and Elias)

Analyzing Practice

Analyzing practice reflects student modeling actions and conversation about decomposing a phenomenon into smaller parts (e.g. objects and variables). Analyzing practices happened when students were selecting images for objects, creating objects, variables, and relationships, or providing information for a model component, such as specifying a variable name, specifying its initial value and description. It was an interesting change that analyzing not only happened when students were discussing or specifying a model component as in WQI, but it also happened when students were creating relationships, which usually was a process of synthesizing. Sometimes analyzing practice resulted from visualizing the model layout. Further, analyzing practice seemed to be more purposeful because most students sought images purposefully and questioned the relevance of a model component to their driving questions or foci.

In general, analyzing was aligned with driving questions and the foci of the models. Students also seemed to purposefully highlight the major components of their model. Charles and Simon, Cathy and Shirley, and Nathan, Lisa and Shaw created STREAM as their first object. As the following excerpt shows, Charles was referring to the STREAM as "our" stream (PV160, Lines 1-2) to contextualize their model.

----------Plan mode
1 (PV160) 0046 Simon: We need this (Stream icon), right?
2 Charles: Yeah, that will be our stream.

The following episode of Cathy and Shirley also shows that students were purposeful in selecting their objects (PV161, 0131, Line 2). Further, Cathy also highlighted the most important object: STREAM (Line 3). Since the modeling practices became more meaningful, student modeling actions and practices were also more concentrated, with fewer moves between modes, as shown in Figure 4.9.

----------------PLAN
1 0131 Begin to create objects.
2 Cathy: oh, that's our sun. [She clicks on the sun icon.]
3 Shirley: no, wait, we need water.
4 Cathy: I know.
5 Drag the stream icon to make a new object.
6 New object: stream, background, Description: this is our steam.

Although Abby and Don created FACTORIES as their first object, they filled in the description as "this is the number of factories near the stream". They talked to each other and Don answered Abby that "we can do this as our stream" (PV166, 0703). Jackie and Elias did not talk about their driving question. Their first object was SUN, which was also the first object they created for their WOI model. This model, thus, was related to their model of WQI although they decided to create a new model. Jackie had indicated that they needed to make a decision between two options at the very beginning "...today we are going to a) look at our old model or b) make a new one (PV164, 0000)." It seemed that their model was still about the influence of SUN, but they did not make it explicit and thus affected their making sense of the whole model later on.

For most of the pairs, there were instances when they also highlighted the more important variables by making the variable the center of the model. For example, Cathy moved the STREAM icon to the middle of the model layout (PV170, 1252, Line 3).

--------------BUILD
1 (PV170) 1252 Students rearrange the variables.
2 All of them have long names.
3 Cathy: okay, now, stream in the middle.
4 Students put the stream in the middle.
5 The sun and weather variables on its left and
6 the factory and plants variables on it right.

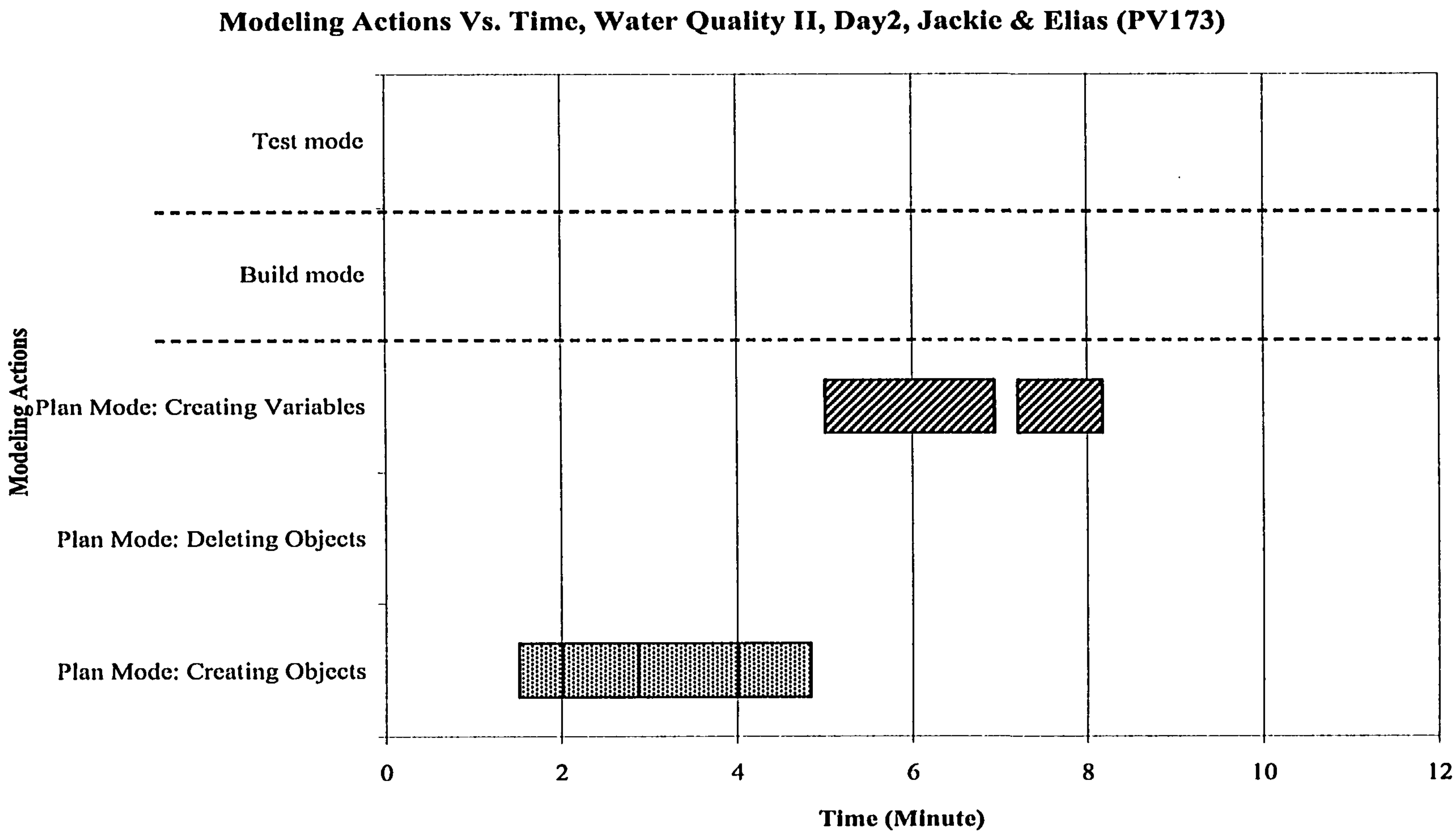


Figure 4.9. Modeling Actions (PV161, Cathy and Shirley)

Analyzing practice seemed to be integrated with synthesizing practice. This means when students were planning or specifying objects, variables, and relationships, they also considered how a model component fit the whole model in terms of a driving question or focus. For example, when planning an object or variable, students might mention its relevance to relationships or how it tied to the focus of a model. The following excerpt shows that Abby and Don, although not fully understanding the ideas of modeling, planned their relationships by looking at the objects they had (PV181, Lines 6-19).

----------Plan mode
(PV181) 0110 Abby: ...so, what was our driving question again?
Don: how people affect the water.
Abby: OK, (looking at the world view and moves the icons)
how many more objects do you want?
Don: two or three more? What do you think?
Abby looks at the screen and rearranges the icons.
Abby: Ok, the people over here make factories and
that affect water quality here. And more factories affect...
Abby then points to the images and presumably draws lines
between the icons of people, factory, car, building and water.
Abby: so we have a line here, then here, then here
(She is actually thinking about the relationships).
Thread one: PEOPLE _FACTORIES_ CARS_WATER;
Thread two: PEOPLE_BUILDING_WATER
Thread three: PEOPLE_WATER
Don suggests the fourth thread: CAR_ WATER
Abby agrees if Don wants to do (demonstrate) oil changes.
Abby suggests having two more objects that humans make effects...
Don agrees ...

The following episode also shows that student analyzing practices demonstrated their synthesized ideas (PV160, 0118, Lines 9-13). When creating an object PEOPLE, students discussed its relevance to their overarching focus: water quality. It seemed that Simon was more thorough than Charles; otherwise, they would not have added more description (Line 7) to make it more accurate. This was an episode where Charles and Simon collaboratively created the description of their PEOPLE object.

----------Plan mode

1 (PV 160) 0118 Charles: now we need some people.
2 Simon: this person [icon]?
3 Charles: yeah.
4 Simon drags the person icon from the palette and types.
5 New object: people, normal, description: people affect the water quality.
6 Charles: now we need some variables.
7 Simon: Any other stuff?
8 Charles: no!
9 Simon: Should we say they affect water quality?
10 How about we say affect water quality in many…
11 Charles: Many ways, many different ways.
12 Simon adds Charles' words to the description.
13 Charles: yeah.

In summary, student analyzing practice is more meaningful and purposeful than were in WQI. Analyzing practice is also more integrated with other practices, such as synthesizing practice, as shown in the above excerpts.

Synthesizing Practice

Synthesizing reflects student modeling actions and conversation about a model as a whole representing its driving question or focus. During WQI, synthesizing usually happened when students were creating relationships and testing their models. During WQII, it happened even at the planning stage before students had created anything. For instance, Abby and Don engaged in synthesizing practices when they were planning to have more objects and variables, as shown in PV181 (0110). Synthesizing happened during analyzing because students talked about relationships when discussing or specifying objects and variables. Further, students were also able to predict what the model would look like.

The following episode shows how analyzing was accompanied with synthesizing in the sense that when students were creating relationships and articulating the rationale (for filling the BECAUSE STATEMENTS), they also created or modified their objects or variables (PV185, 1000, Lines 7-14). Cathy wanted a turbidity variable between family and thermal pollution (Line 7). According to their description, "the amount of families" increases the turbidity and then increases the level of thermal pollution. Also, although Shirley made most of the suggestions, this time Cathy was very clear and persistent in putting the idea of turbidity in the model. Figure 4.10 of this class period shows the integration of the modeling practices. For example, students discussed relationships when creating objects (#1). They discussed objects when creating relationships (#2 and #3).

-----------Build mode
1 (PV185) 1000 New relationship: people--> thermal pollution.
2 Shirley: wait, cancel [the relationship].
3 Cathy: yeah.
4 Move the people variable to the top.
5 Move the family up.
6 Shirley is going to make a relationship between family and thermal pollution.
7 Cathy: no, no, no. We forgot to make a little icon about turbidity.
8 Shirley: why does turbidity matter?
9 Shirley: what is turbidity?
10 Oh. Let's make a turbidity icon after we do this.
11 [Creating a relationship between family and thermal pollution].
12 Cathy: no, but see, it wouldn't be connected to that because of the turbidity.
13 The turbidity should be connected to that [thermal pollution].
14 Shirley: okay, let's go to the plan.

The following episode shows that Abby was able to predict the model's behaviors while she was only at the stage of creating objects and variables (PV166, 3000, Lines 3-4). She would not have been able to do this if she had not gone through the initial modeling cycle: WQI. However, her memory was not very accurate because there were straight lines on the simulation graph for not having relationships between variables, not because of the lack of objects or variables.

---------Plan mode

(PV166) 3000 Abby rearranges the icons.

Abby: ok, this affects this…

Abby: we need more things (objects and variables), otherwise (the relationships) will be like straight lines showing that we are stupid…

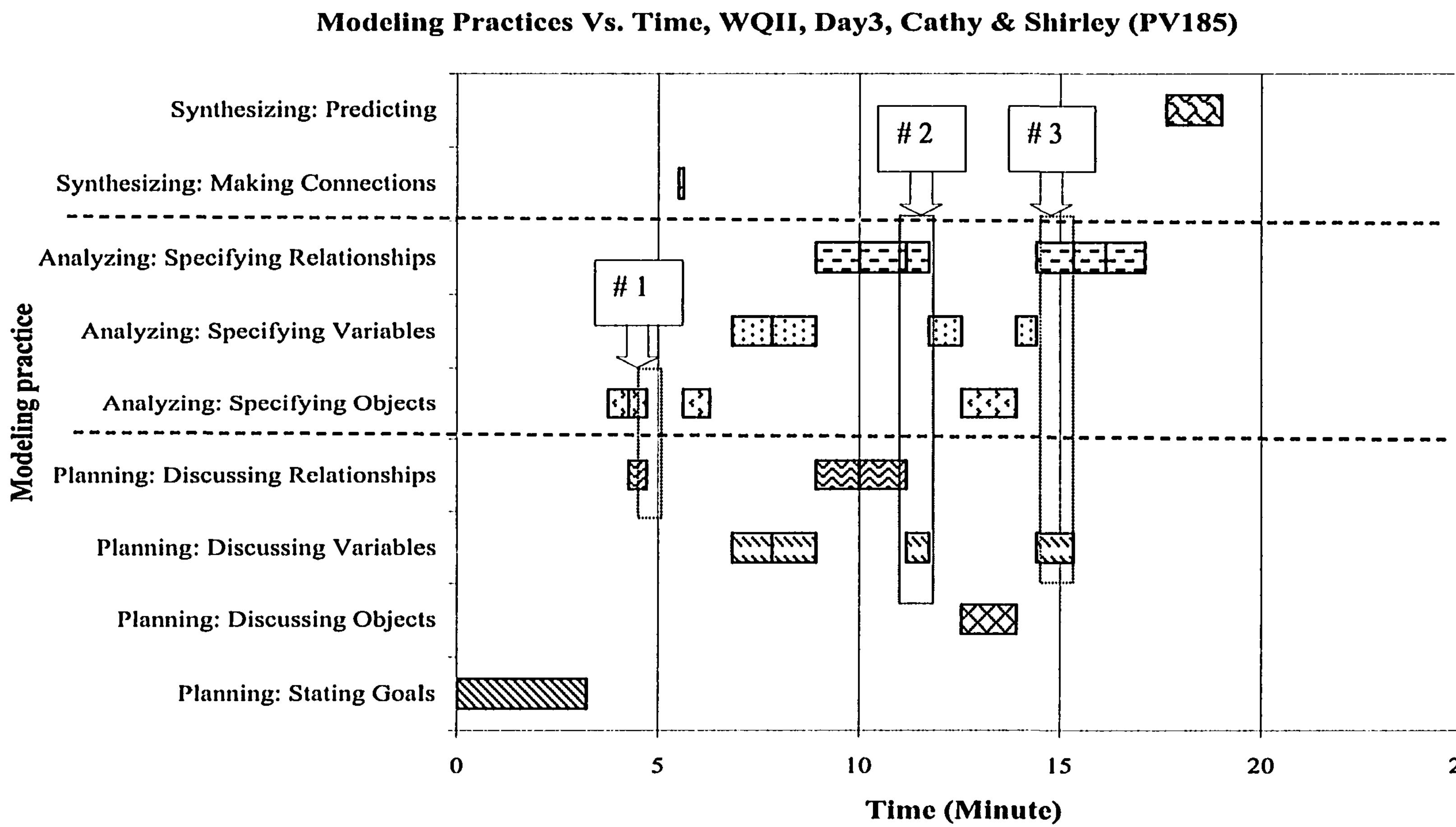


Figure 4.10. Modeling Practices (PV185, Cathy and Shirley)

Synthesizing was an ongoing process along with visualization of the model and testing. The following example shows that the interaction with the model they created helped Abby and Don to specify a new object (PV166, 2647, Lines 1-7).

(PV166) 2647 Abby: all right, now what should we do?
Don: People (laugh).
Abby: what else affects the stream?
Don: well, we've got all the people to build all of the stuffs.
Abby: We know that, that's our question.
Don: so what?
Abby: we need the things that actually affect the stream! ...
All right, the more people, the more factories, then more cars they need...
New object: PEOPLE Normal
Abby: description? People around the stream or working in the factories that around the stream.
Don murmurs but does not show sign of disagreement.
Abby types the description.

The following is another example showing that visualization helped students to synthesize (PV173). Jackie and Elias rearranged the model layout so that the variables would be in positions that were meaningful to them.

(PV173) 1120 Jackie: Let's move all the Sunlight ones up to the top.
Jackie: Put clouds right next to them.
Elias: What do clouds affect.
Jackie: Let's just get them all in line.
Jackie: Amount of clouds to sunlight.

Synthesizing was difficult when students were accommodating new concepts of a domain (e.g. season in a model of thermal pollution). In Class I, there were three groups of students that had the driving question around thermal pollution (Charles and Simon, and Cathy and Shriley). The teacher called a meeting before the first modeling period so that students could generate some ideas about their model. Understanding the effect of seasons on thermal pollution became an important point the teacher wanted to emphasize. On Day 1, Cathy created an object: WEATHER and filled in the description as the SUN in order to represent the impact of the sun on thermal pollution (PV161, 0207). The following episode shows how the teacher tried to guide students to think about the impact of the sun during different seasons (PV161, 0500, Lines 14-18), but students did not pay attention to the teacher's suggestion (Line 23).

(PV161) 0500 Modify object: SUN, description: this is the weather...
Cathy: wait, why did we call it weather?
Shirley: because when it shines, it causes the stream warm up.
Cathy is making noise to the mic.
The teacher tells her not to do that.
Teacher: so you have sun shining cause the water warm up.
Now, Remember this winter when we had sun shining,
did you have thermal pollution?
Cathy: no.
Shirley: no, because we didn't have a turbidity problem.
Teacher: okay, let's say you have a lot of turbidity.
Would you still have thermal pollution?
Shirley: yeah, because the sun...the dirt would absorb the sun.
Teacher: maybe, well, there is one other factor.
What about in the middle of July when
the sun is shining versus September sun is shining?
Shirley: there are leaves [that cause high turbidity].
Teacher: okay, true. But there is something else.
Cathy: well, the sun warms up the dirt. There is a great deal of turbidity...
Shirley: the dirt will absorb the sun that may cause thermal pollution.
Shirley and Cathy finish their description.
Teacher: there might be one other variable.
(Students ignore the teacher's suggestion.)

Students finally created an object SEASON (PV170, 4004) and its variable, (PV185, 0750) and finally made the values of the variable correct (PV185, 1110) when they created a relationship using the variable.

Charles and Simon also experienced a similar process in order to include this new concept. They first created a SUN object (PV160, 0505), as suggested by their peers during their first meeting, to represent the influence of SEASONS on thermal pollution. When they rethought the idea, they rejected the idea and deleted the object SUN. The following excerpt shows how they made the decision (PV169, 2011, Lines 2-8).

(PV169)
2011 Simon: so turbidity? [They move cursor between turbidity and sun.]
Charles: Do we really need sun?
Simon: well, the sun does heat up like turbidity in the water.
Charles: yeah, but only when it's turbid.
So I guess we don't need sun, 'cause it's always gonna be sun.
Simon: yeah (hesitantly).
Charles: it (sun) doesn't really matter.
Simon: we can just delete turbidity and sun all together.
Charles: I think we need turbidity.

After the teacher called a second meeting with the three groups that were working on thermal pollution (PV169, 3435), they added a new object: TIME OF THE YEAR. The description was "this will be the seasons". They customized the initial value of the variable they created as spring/summer/winter (PV169, 3606) but modified it to "Winter, Fall/spring, and Summer" after testing and found the anomaly on Day 3 (PV175, 0357).

In summary, synthesizing is purposeful as defined in Chapter three when there is good understanding of how the modeling program works and awareness of the alignment between the driving question and the model's content. Good synthesizing leads to a more accurate and functional model.

Evaluating Practice

Evaluating practice reflects student modeling actions and conversation about making judgment of the quality of a model using certain criteria. Evaluating happened when students reflected on their model with the help of visualization. As the modeling program was designed, the test mode was for evaluating and synthesizing. Students made judgments according to the model's behavior. It seemed that the need for presentation promoted students to evaluate their model, as shown in the episode of Abby and Don (PV166, 3000).

Evaluating was not obvious at times other than during testing. A meaningful evaluating practice looked like the following example. The model's behavior was what the students expected (PV169, 1308, Lines 3-5). Charles even made further connection to the real world problem that their model described (Lines 6-7).

-----------TEST
(PV169) 1308 Charles: play, oh, we have to do the meter thing.
Open meters. Enlarge the simulation graph.
Play simulations and change the values of meters.
Charles: if there are tons of people, there is more heat and there are
more hot water dumped. If there are less people...
See, this is one of the problems in the large cities.
Simon: okay, it works.

Evaluating helped students to discover anomalies from a model's behaviors when running a simulation, thus leading to modification or revision of the model. Therefore, evaluating improved the quality of the model. Evaluating practices were also an opportunity for students to deepen their content understanding when revisions were made. The following example shows that after testing the model, Jackie decided to put turbidity and conductivity in the model so that it represented a more sophisticated view of how things affect water quality (PV173, 2215, Lines 10-11). Students actually later decided to put all the five tests of water quality into the model.

---------- TEST
(PV173) 2215 Jackie calls up all the meters.
Jackie: It is very complicated.
Run test.
Jackie: There is not a lot of sun, so there are not a lot of plants.
Jackie: How many cars are there?
Students are checking each meter value.
Jackie: I guess there are not enough plants?
Manipulate independent variable meter.
Jackie: Now if we go to high, ooh, there, that's bad.
Jackie: hey, let's make water quality into conductivity, turbidity,
so we know exactly what we have.

In summary, evaluating is implicit. There were no specific criteria that students mentioned. Evaluating could help students to revise their model based on the results of running a simulation in test mode. Sometimes, students are able to evaluate their model by visualizing and reflecting on a model's layouts.

Publicizing Practice

Publicizing practice reflects modeling actions and conversation when student pairs presented their models to the others or their classes. Publicizing was scheduled at the end of this modeling cycle when students were supposed to present their models to the whole classes. Sometimes during the modeling process, a teacher or a researcher might ask students to show them their models or the students had questions so that they needed to articulate their model as well as their questions.

Publicizing also allowed students to articulate their thinking and reflect. It also provided a need for students to be serious and motivated. When a teacher or a researcher was with students, publicizing usually led to critiquing and useful comments for further modification. Therefore, publicizing with specific need, such as for teacher's feedback, from students seemed to be more purposeful and meaningful. The following example from Lisa and Shaw's modeling period is illustrative. Lisa proposed their driving question as "how do houses affect water quality?" at the beginning of the cycle (PV163, 0210). However, since both students proposed model components without explaining to each other, they were not able to communicate their idea well. This publicizing opportunity, thus, became an opportunity for students to critique their own model, too. Especially for Shaw, he was almost excluded because Lisa seemed to dominate typing and operating the mouse. Shaw finally found a time to express his opinion (PV172, 1615, Lines 4-9 and Lines 11-18). With the teacher's feedback, Lisa started to revise the model (PV172, 1702, Lines 20-33).

---------BUILD
(172) 1615 Lisa goes to build mode to show teacher Carol the mode.
Shaw then follows the arrows, listing how each variable is related.
Lisa: the clouds affect sun...
Shaw: we don't need either of these (pointing to relationships)....
Shaw: Look, it's like the stream.
(Shaw is holding the cursor while Lisa is silent)
Shaw: The number of people there are affects...no..
Shaw: How much they use the car, how much it pollutes,
Shaw: And how much garbage they create.
Teacher: OK.
Shaw: when there are people there, they have to go to factories to work,
then the factories ...
Lisa:... that's the garbage.
Teacher: so the relationships just sort of out there, right?
Shaw: yeah...we kind of have those at the beginning...
We kind of change our...like.
Lisa: we do not need this (a relationship of clouds).
Shaw: right.

1702 Lisa goes to plan mode, then goes back to build mode.
Deletes Relationship CLOUDS to SUN.
Create Relationship CLOUDS (the other one) to SUN.
Teacher: Finish the "because statement".
Lisa: So, the air pollution?
Shaw: We have to change it to decreases.
Because the more clouds the less heat gets to the stream, and less heat makes the
DO go up, since cold water can hold more.
Teacher suggests changing the wording of the description.
Lisa: This is like how dark the clouds are, from the pollution.
Teacher: Is it how dark clouds are, or the fact that there are clouds.
Shaw: the fact that there are clouds.
Teacher: how dark they are depends on if it is storming or not.
Lisa: OK.
Modify Variable - description for CLOUDS.

Without the teacher's intervention, Lisa would not have had any input because Shaw "freaked out" (PV172, 1245). She also did not ask questions or use any resources. She did not feel the excitement, either, because she finally stopped working for a while.

When Shaw asked, Lisa answered that she was sleeping (PV172, 2645). Therefore, these two episodes also show that it was very important for students to collaborate and talk to each other in order to exchange ideas, clarify one's thinking, and learn from each other.

For the publicizing of student models to the classes, it seemed that the teachers were the key persons to provide comments and feedback. Students seldom took the initiative to provide their comments unless asked by a teacher for a specific reason, as shown during Cathy and Shirley's presentation (CV103, Appendix K).

In summary, publicizing provides opportunities for students to articulate, and reflect on their model. It also allows students to receive comments and feedback from peers and teachers. Publicizing practice in the presence of teachers seems to be more productive in terms of the amount of useful feedback students could receive for improving their model.

Other Dimensions of Student Learning in Modeling Practices

Metacognition

Students used a variety of ways to monitor their process. Some students, such as Jackie and Elias, planned ahead so that they could make use of their notebook as a resource for ideas. Students frequently referred to their driving questions when discussing and specifying a model's components. Students might also follow the teachers' instruction closely to gauge their progress. And they were also aware of the need for presentation. The increase in their content knowledge and modeling knowledge also seemed to facilitate the development of metacognition.

Simon followed the teacher's instruction closely. The following example shows how the teacher's instruction influenced student decisions. It took some effort by Charles to persuade Simon to have this one more object (PV160, 0556, Lines 5-10) because Simon always kept the teacher's instruction in mind when deciding "course of action".

--------Plan mode
(PV160) 0556 Simon: okay, we have three.
No, wait, we have four (objects).
Simon scrolls and rearranges the icons.
Charles: we still need sidewalk stuffs.
Simon: she (Teacher Alice) said we could only have four (objects).
Charles: no, she didn't.
She just doesn't want people to have tons of stuff.
Simon: yes, she did.
Charles: we still need sidewalk and we need pavement.
We just need one more, pavement. That's it.
New object: SIDEWALK AND PARKING LOT.
They can't find an icon they want from folder
Charles S: just do the blank one. (In a persuasive and soft tone)
They leave the icon blank. Then fill in the description.
Charles: when it rains, it will heat up the water.
Simon: wait. (Talking while typing)
If the air temperature is hot and it rains, the sidewalk and parking lot
Charles: will heat up the water.
Simon: okay, that's it.

Metacognition seemed to decide whether students were purposeful. On the other hand, becoming more purposeful could be a sign of improved metacognition. For example, students had learned to tell each other their driving questions so that they could have shared understanding and foci. As mentioned previously when reporting planning practices, most student pairs prepared, proposed, and shared their driving questions at the beginning of this second modeling cycle. Therefore, they were able to be more purposeful in deciding what to include in the model.

Filling in the descriptions or because statements also seemed to be a way to improve student metacognition because it requires students to think through what they were supposed to build in a model and why. However, they had to fully understand what they were supposed to write for the descriptions. The following excerpt shows that Cathy did not know what exactly the description was that she was supposed to write. After the teacher confirmed the example that Shirley proposed, Cathy decided to modify several descriptions of the objects they had created (PV161).

------------Plan mode
1 (PV161) 0450 Teacher Alice comes.
2 Teacher: Did you carefully write your description?
3 Cathy: what are we supposed to write in the description?
4 This is a factory?
5 Shirley: this is a factory that could dump hot water for cooling water.
6 Teacher: perfect.
7 Cathy: okay, then we have to fix another one [objects' description].
8 Teacher: did you save yet?
9 Shirley/ Cathy: yeah.

On the other hand, students also showed their metacognition more obviously when a practice was less meaningful (e.g. Abby and Don said they did not understand and they asked questions frequently, PV166). In general, students were more focused and productive in WQII than in WQI in terms of the number of model components and the quality of the models (Average number of variables in WQI, 8, relationships, 9; Average number of variables in WQII, 11, relationships, 13). This could be a sign of improved metacognition. Furthermore, the improvement could be attributed to a combination of improved content and modeling knowledge, as well as metacognition.

In summary, students improve their metacognition because they become more purposeful in terms of how they collaborate to be productive: They share their driving questions; they use resources more frequently, and ask more questions.

Content Knowledge

The first sign of improved content knowledge was the more meaningful and purposeful use of new terms, such as the five water quality tests, decomposers, eutrophication, aquatic life, photosynthesis, and so on. More students used the bell-curved relationships accurately. Students, thus, went further to be more specific in showing the mechanisms of how things affect water quality in their models. They also tended to be more holistic in describing the phenomena by including all five water quality tests in their model, such as Jackie and Elias', and Nathan and Kelly's models. The following is the model of Nathan and Kelly in WQII (Figure 4.11).

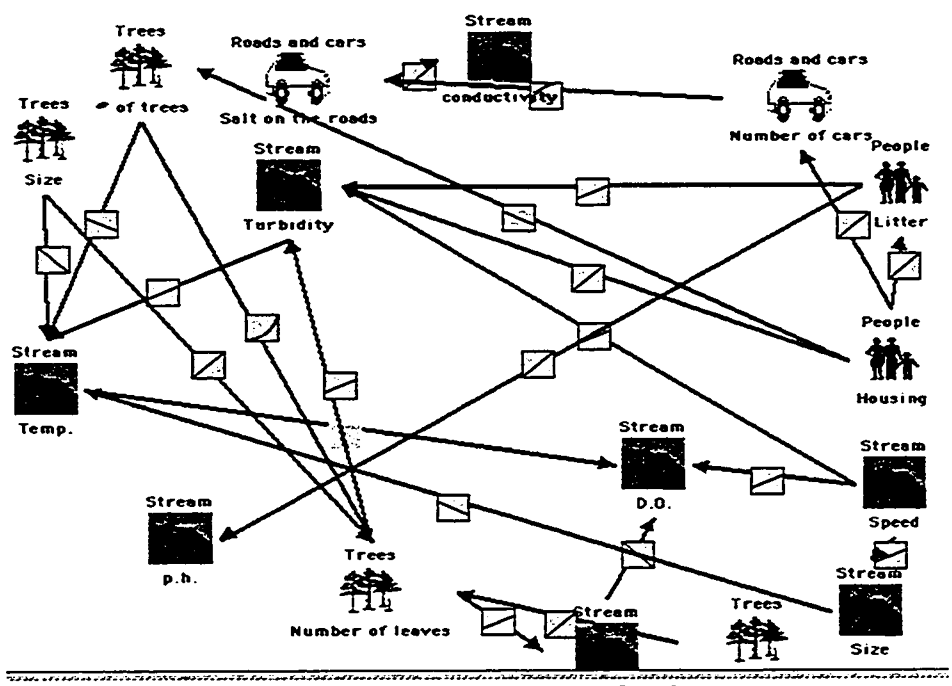


Figure 4.11. Nathan and Kelly's Final Model of WQII

The following example shows how richer content knowledge led to more accurate description of the FACTORIES object. Charles was skeptical about how chemicals would affect thermal pollution (PV160, 0216, Lines 8-15). However, after Simon argued with him by saying that the teacher said so, he seemed to accept the idea (Lines 16-17). Even Simon encouraged him to ask the teacher, but he did not do it (Lines 18-19). On the next day, Charles asked the teacher "what chemicals affect thermal pollution?" (PV169, 0851). Teacher Alice encouraged students to check their notebooks. Later, Simon confirmed that he was correct after checking his notebook (PV169, 0916).

--------Plan mode

(PV160) 0216 ...
New factory: FACTORIES, normal, icon from the folder.
Description: dump hot water.
Charles: would that be a variable?
Simon: no.
Charles: oh, it won't be high, medium, low.
Simon fills in description.
He puts something about chemicals in the description and Charles disagrees.
Charles: but we are not doing anything about chemicals.
Why do you like chemicals?
Simon: because chemicals can heat the water too, can't they?
Charles: can they?
Simon: yes.
Charles: chlorine dumping into the water...wow...it's hot
[Amusingly]. I don't think so.
Simon: that's what she (the teacher) said last time.
Charles: okay, then.
Simon: why don't you ask her?
Charles: no.

In summary, a richer understanding of content leads to a more sophisticated model: Students tend to think more holistically when they understand more about water quality in terms of an integrated system.

Inquiry Experience

The teachers tried to encourage students to use their investigation experiences. For instance, teacher Alice told students the news she heard on the radio on her way to work (PV185, 0530). However, there was still a lack of connections between student investigation and the models they built. The knowledge might be tacit because students were creating a more general model of water quality. However, it seemed that students had not developed a habit of citing their investigation to support their decision making. The following was one of the few instances showing how student Abby and Don used their investigation data to decide the initial value of their variable: the number of buildings (PV166, 2400).

-----------Plan mode
(PV166) 2400 New variable: building: number of building
Students discuss about what to fill in the description window.
Abby: how many of buildings that are in the distance that can affect the stream.
Students now talk about the initial value.
They change the range of the numerical initial value to 0-20
and put initial value as 20.

Another reason for the lack of connection might be that students did not choose the stream that they investigated, as shown in the above example. In one class, teacher Carol told students that they did not have to create a model of their stream, it could be a general model (CV165) of water quality. On the other hand, the examples she and the students provided were mostly based on the stream that students investigated (CV129 and 132) at the very beginning of WQI.

The following example raises a question of whether student life experience or just "common sense" played a role in this topic of "common" science that students are experiencing every day.

--------BUILD
(PV160) 0130 Switch to build mode to see the variables they have.
Charles: did we already put that in there?
Students find the time of year variable.
Simon: so we don't need sun, do we?
Charles: No, because we're talking about ""time of the year".
Charles: oh, so what does "time of year" affect?
Simon: ...maybe thermal pollution.
Charles: oh, yeah, that is supposed to be directly...
Wait, no, that goes to sidewalk and stuffs.
Simon: yeah, sidewalk and thermal pollution.
Does it also change the temperature indirectly?
Charles: yeah, but for a big space.

In summary, students usually do not have the habit of using their investigation for decision making although the teachers tried hard to influence them using examples and modeling the practice themselves.

<u>Modeling Knowledge</u>

Student modeling knowledge was captured when they expressed that they did not understand issues of modeling, or their modeling actions showed their lack of understanding of modeling. For example, a variable name might not be a measurable trait of the object that it attached to.

Student modeling knowledge seemed to be improved because most students were able to create more accurate and functional models. However, modeling knowledge might not be improved automatically. For example, almost no students really mentioned the purpose of their model and what criteria to use in order to evaluate their model. Very few students consistently made connections between their investigation and their model of water quality.

Modeling knowledge seemed to impact the purposefulness and meaningfulness of student modeling practices. The most significant example was from Abby and Don. The following example shows that she did not know what a variable was when she was creating a variable for the STREAM object (PV166, 0933, Lines 3-8). However, students remembered "dependent variable".

-----------Plan mode
(PV166) 0933 Abby then brings up the variable editor and
highlight the variable name window.
Abby: what is the variable?
There is only one stream.
Don: how polluted this is?

Abby: we do not know because all the stuffs are polluting it.
(Complaining) Why do we have so much trouble with this.
This is not hard concept. Why don't we understand.
Don: We need to write something down to explain it.
Abby: what do you mean? No. I do not understand...
Like "how..."This is a dependent variable, right?
Don: yeah. What we are talking about?
Abby: I do not understand what is the question here.
[Abby seemed not to understand the concept of a model and purpose of a model.]

It seemed to be a difficult process for students to understand the concept "variable". Abby actively sought help from the researchers. However, the following episode shows that her difficulty seemed to be persistent (PV166, 1340, Line 9). Abby asked a researcher for help and this was the third time she asked a question about "variable". It is difficult to provide an interpretation for Abby's difficulty given intensive scaffolding that two researchers had provided. Students might not understand or consider the model as a dynamic system. This idea was not explicit to students and seemed not to be emphasized in teachers' instructions.

(PV166) 1349 The researcher tells them that one object can have
more than one variable...
For example, you as one person, you can have height, weight, and eye color...
Stream...stream has quality, like pH.
Abby: how to do that?
The researcher tells Abby to click on "variable" button
and make another variable, like pH.
Abby whisper to Don after the researcher leaves.
Abby: I do not understand that.

In summary, it seems that some aspects of student modeling knowledge did improve just because they were doing modeling. For example, the concept "variable" and the idea of considering a model as a system did not occur to Abby and Don naturally. However, given most student progress, the "need-based" instruction in the scaffolded learning environment seems to be the best way to teach students modeling knowledge.

Collaboration

The data showed that collaboration was very critical for deepening student understanding of both content and modeling. Students who had good rapport tended to talk to each other naturally and communicated to each other in a respectful manner. For example, Simon and Charles; Abby and Don; and Jackie and Elias fully communicated their ideas and asked for each other's feedback. Nathan and Kelly did very well in WQI, but Kelly was not able to attend classes during the modeling periods for WQII.

However, good rapport might not necessarily improve the exchange of ideas. While Cathy and Shirley talked to each other naturally, they also kept their independence in their ideas. They did not hide their disagreement when they presented their model to the class (CV103, Lines 18-19 and Lines 21-28). The following excerpt shows this point.

----------Build mode
1 (CV103 and PV190) 0220 Cathy: There we go.
2 Hi. Our driving question is what are the causes and affects of what...
3 Shirley: thermal pollution [laugh].
4 Cathy: Okay these are objects, kind of obvious.
5 People, factories, cities and aquatic lives
6 and the reason there are two people is because this family,
7 this family is a polluted family and
8 this guy is a one who could be building a factory.
9 So they're like different, represent different things.
10 (Cathy also clicks in the descriptions to show other Students)
11 Another student: You made the same object in two variables.
12 Cathy: Yeah we didn't want to do that. I want them both
13 to be people and you do not feel like that [Some Students laugh].
...
14 0525 Teacher: And just when you're doing a really nice job
15 talking about how it affects this and affects that,
16 but you're not telling us exactly how it affects it.
17 Does it affect it in a positive way or does it affect it in a negative way?
18 Cathy: negative.
19 Shirley: both way.

Teacher: So just make sure you interject that part.
Cathy: Okay because well the family is not good because they're polluting
and that's creating or not polluting they're like around the stream
which is creating a erosion.
Shirley: Well, like it depends because if there's not much
family when your building it or testing it or whatever,
then there aren't much turbidity.
Cathy: Mm, hmm, and, and then
(Cathy looks at Shirley seems to seek support and Shirley smiled back),
like this person is building the factories and that's not good
and then the factories...
Cathy: (factories) Are dumping chemicals in the stream
which causes the water in the area where they're dumping to have a causes the
stream to heat up, which would cause a difference in the temperature between that
and another location. Okay?
Cathy: That's all.

When students were not able to collaborate well, the modeling practices could be less purposeful and meaningful, as well as less efficient due to the lack of communication, as shown in Lisa and Shaw's case. On Day 2, Lisa almost excluded Shaw as before. She made deletions (#1, #2, and #3) and modifications (#4 and #5), jumping between different modes, as shown in Figure 4.12. She even engaged in off-task activities (#6), which was rare across the three modeling cycles. This kind of working "solo" seemed not to be motivating and exciting. In the end, Lisa answered that she was sleeping when Shaw asked because he did not see any actions by Lisa (PV172, 2645). Shaw was also very disappointed. As happened before, he frequently blew into the microphone that was for data collection. This could be the reason that he did not come the next day (PV178).

In summary, most students collaborate well, with the exception of Lisa and Shaw. When students do not collaborate well, their modeling practices are not efficient and are less purposeful, as shown in the case of Lisa and Shaw.

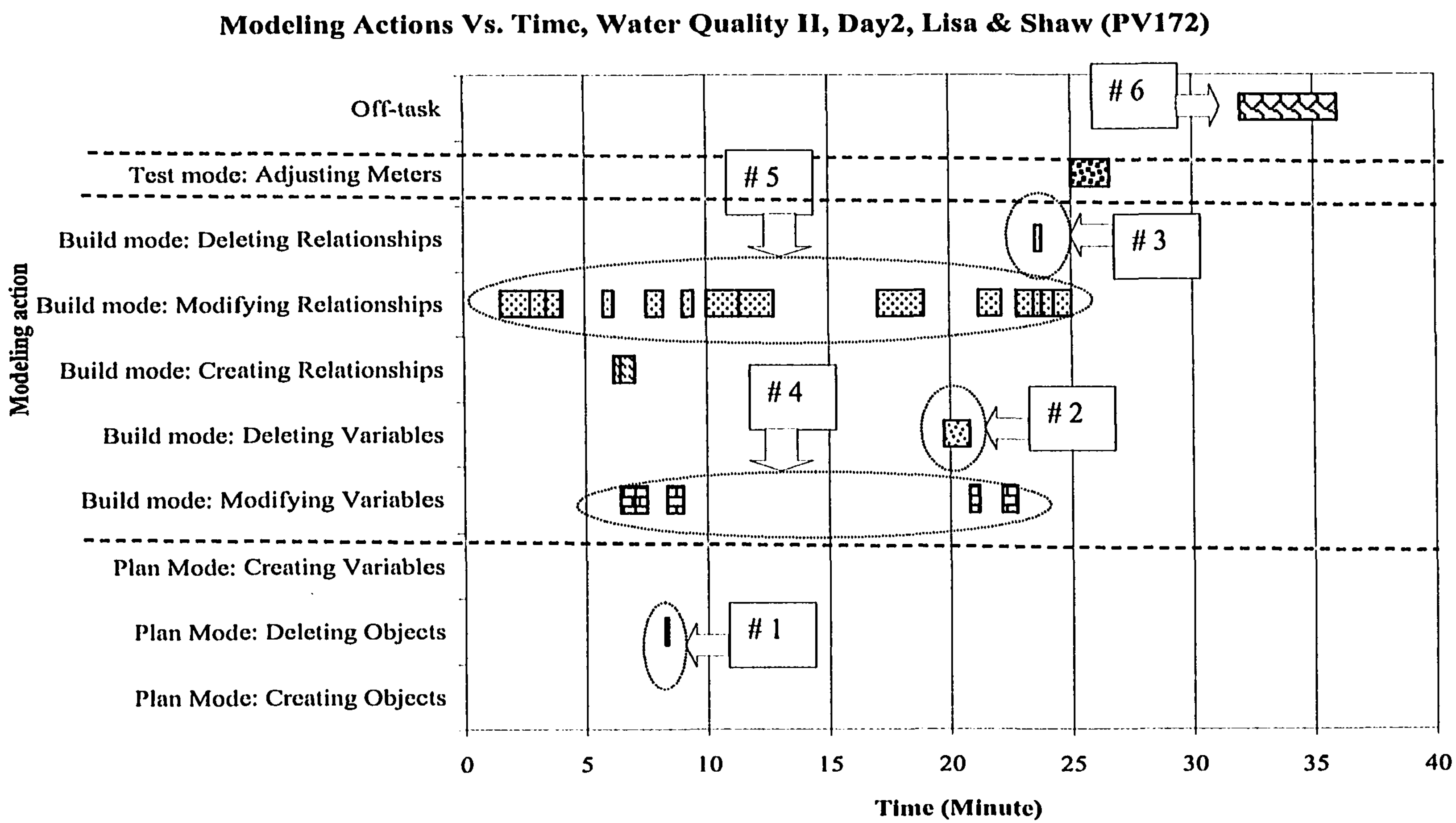


Figure 4.12. Modeling Actions (PV172, Lisa and Shaw)

Changes in Student Modeling Practices (WQI to WQII)

Compared to the practices of WQI, during WQII, students seemed to be more purposeful in planning their model at the beginning of the cycle. In general, their planning was more aligned with the driving questions or foci of their models because they questioned the relevance of a model component to the focus of their model.

Student modeling practices seemed to be more integrated in WQII. Planning seemed to be an ongoing process that happened throughout the whole modeling cycle. When students were supposed to discuss and specify objects and variables to analyze a system, they also considered how to position them in relationships. When students were creating relationships, they might realize the need for deleting, revising, or building objects and variables. Evaluating not only happened during testing as the program being purposefully designed for, but also happened with the help of visualization while other practices occurred.

More importantly, the way students looked at the phenomena had changed. Based on student models and presentations, the students seemed to have a more holistic consideration of the phenomena. Their driving question, therefore, changed accordingly. For example, Charles and Simon changed their driving question from "How does conductivity affect water?" to "What are the effects and causes of thermal pollution?" When presenting the model in WQII, Nathan explained that their model of WQII showed how humans affected almost everything in the stream (CV102).

During interviews (Tape 300), teachers reported that in WQI they suggested that students focus on one aspect of the water quality tests, such as DO or turbidity. However, teachers did not emphasize connections between the five water quality tests. Over time, students realized the connections between the tests so they changed their driving questions and moved from using one test affecting water quality to a more comprehensive analysis of variables that affect water quality.

There seemed to be little change in terms of the design of the classroom environment. However, minor revisions were made. For example, students used a new version of the modeling program: Model-It 3.0. The meters and graphs in the test mode were of different colors. The meter colors were associated with the colors of the graph lines. Also, students had gone through their second round of water quality investigation so that their content knowledge was improved. Again, the teachers emphasized collaboration. Teachers also asked students to build a simple model, and then expand it in order to become familiar with the modeling procedures as quickly as possible. Also, students had less time to create their models because of the time constraints of the curriculum.

Student Modeling Practices: Decomposition Unit

Planning Practice

Planning practice reflects student conversation in light of what to build in a model before they took any modeling action. Students had less time for creating models on decomposition than they had in the water quality unit. Students in Class I had two and a half days to finish their models before presenting them to the class. There were even tighter schedules for students in Classes II and III. They only had two class periods to finish their models and present them to other groups in the classes. A change for the target students was that they were either swapped or totally changed. Therefore, the target students were all in new pairs or groups although most target students remained in the same class.

None of the students showed that they had planned their model before the modeling cycle. Except for student Jackie and Elias' groups, all of the pairs talked about their driving questions at the very beginning of the modeling cycle. The teachers did not give homework asking students to plan for their models and they required students to discuss what they wanted to build in a model. Students seemed to have no difficulties in deciding what to build in their model. Further, when filling in the critique sheet (See Appendix S for an example of the sheet) that the teacher requested at the end of their presenting and publicizing event, Jackie mentioned their driving question as "How does water affect the rate of decomposition?" This showed that Jackie and Elias had agreed on their driving question for the model.

All the pairs mentioned the need for driving questions at the beginning of this cycle and they were all able to articulate their driving questions except for Elias' group. Student driving questions were also the driving questions in their investigations of decomposition. A driving question might have been a shared understanding of students in a pair or group. However, Elias's group was special. Although he also asked Shaw and Zech in his group what their driving question was, neither they nor Elias could tell what their driving question was (PV195, 0330).

Since none of the students had a plan for the model before the modeling cycle, planning became obvious at the beginning of the modeling cycle. Since students had shorter period of time working on the subject matter (the module lasted six weeks comparing to four months of WQI) and there seemed to be a closer alignment between student investigation and their model, deciding on how to organize and represent their ideas became ongoing processes for most of the students. A typical planning practice at the beginning of a cycle looked like the following excerpt. This was a new pair of students who were both target students in different pairs in the water quality unit. Simon acknowledged that they needed to talk to each other about their plan and Cathy agreed (PV192, Lines 1-2). Since they also did comparative experiments, they both thought that they could start with the two decomposition towers as their main objects (PV192, 5-8). This was very natural because an object was a physical entity that students could see or understand that it existed. However, conceptually, students were not ready for the abstraction of a variable in representing the condition of comparison. Their driving question was "How does the temperature affect the rate of decomposition?" (PV 192, 0258).

1 (PV192) 0000 Simon: so we have to talk about how we're gonna to do this.
2 Cathy: right.
3 Students choose "decomposition unit" (when launching Model-It).

--------------PLAN
4 0030 Cathy: okay, so what are we gonna do?
5 Simon: maybe we should uh...we can say like a warm bottle or something...
6 Cathy: we should have two main objects.
7 We have a warm bottle and a cold bottle.
8 And we can build it up from that.

The same idea of starting from two towers (columns) also occurred to Alisa and Charles, and Abby and Ahmad. Jackie and Elias did not start with the two tower idea because Jackie told Sasha that there seemed to be no difference between columns one and two (PV194, 0512). This could be the reason that they did not start with the two-column idea. Nathan's group did not start from the two-tower idea either. They were not satisfied with the images on the image palette so they quit the program, reopened it, and selected "water quality" unit in order to make use of the images of water quality.

It was not clear how Elias's group did their investigation because none of the three students was able to discuss their driving question. Their planning seemed to be fast. Elias admitted that he did not know what he was doing (PV195, Line 3). Shaw did not understand either (PV195, Line 5), while the other group member, Zech, usually did not participate. Elias encouraged him by recalling their modeling experience of water quality unit (Lines 6-7), but Shaw said that this was different (subject matter) (Line 8). After finally deciding on the independent variable *worm* (Line 13), Elias decided to use all the materials they used as "dependent variables". They created the model in this single class period. However, the model was simple and much less synthesized compared to the models of the other student pairs or groups. Given the fact that the three students were basically lower achievers, their content knowledge, investigation experiences, and modeling knowledge might have limited their making sense of the nature phenomenon. It is even possible that they did not understand their investigation, and so they could not tell their driving question.

-------Plan mode
1 (PV195) 0507 Shaw: There is already worm in (the image) there.
2 (Students are noticing facets of the decomposition tower picture)
3 Elias: I don't know what I am doing.
4 Elias: New variable…Our variable, what is our variable.
5 Shaw: I have no idea.
6 Elias: Let's look at our sheet. It's kind of weird….
7 C'mon we have done this before.
8 Shaw: Not with this stuff.
9 Elias: Same thing, Think like water quality.
10 Elias: We need one independent variable... worms!
11 Create variable: DECOMP-worms, initial value high, has description.
12 It seems that Elias is typing: a lot worms, more decomposition.
…

(After specifying the variable WORM-worm)
1006 Elias: this is the independent variable.
Shaw: yeah.
Elias: Let's go to the dependent variables.
Does anyone have the chart on them,
Shaw: what chart?
Elias: the chart with all our things on it.
Elias: Yeah.
Elias: Go get it so that we can put all of them here.

In summary, students become more efficient in planning their models even without any plan before the modeling cycle. Students demonstrate a common understanding that a driving question is necessary at the very beginning of this modeling cycle. Planning is an ongoing process for students and it is purposeful. The planning practice for Elias's group seems to be simple and clear, but it resulted in a simple and much less synthesized model. This exception could be related to their investigation experiences. Their understanding of content seems to be less synthesized compared to those of other target students.

Analyzing Practice

Analyzing practices reflects student modeling actions and conversation about decomposing a phenomenon into smaller components such as objects, variables, and relationships. For students who started from the two-column idea, a typical path of modeling actions looks like the following graph (Figure 4.13). It shows that students experienced frequent modifications to the objects around the idea of two columns (#1) when they decomposed the phenomenon into smaller parts. Modifying objects was very rare in the water quality unit. Since student models were more aligned with their investigation, the way they did their investigation seemed to influence how they built their model. They finally could merge the two columns into one. Whether it was the influence of temperature, worms, or water, they could either increase or decrease in two directions so that there was no need to have a cold column that was in a refrigerator or a warm column at room temperature. For the same reason, there was no need to have a column that had more worms and another one that had fewer worms. Therefore, analyzing practice seemed to be accompanied by synthesizing practice in order to reach such abstraction. Once students had thought through this process, creating variables and relationships seemed to be a natural procedure and went smoothly and efficiently, as shown on the chart (Figure 4.13).

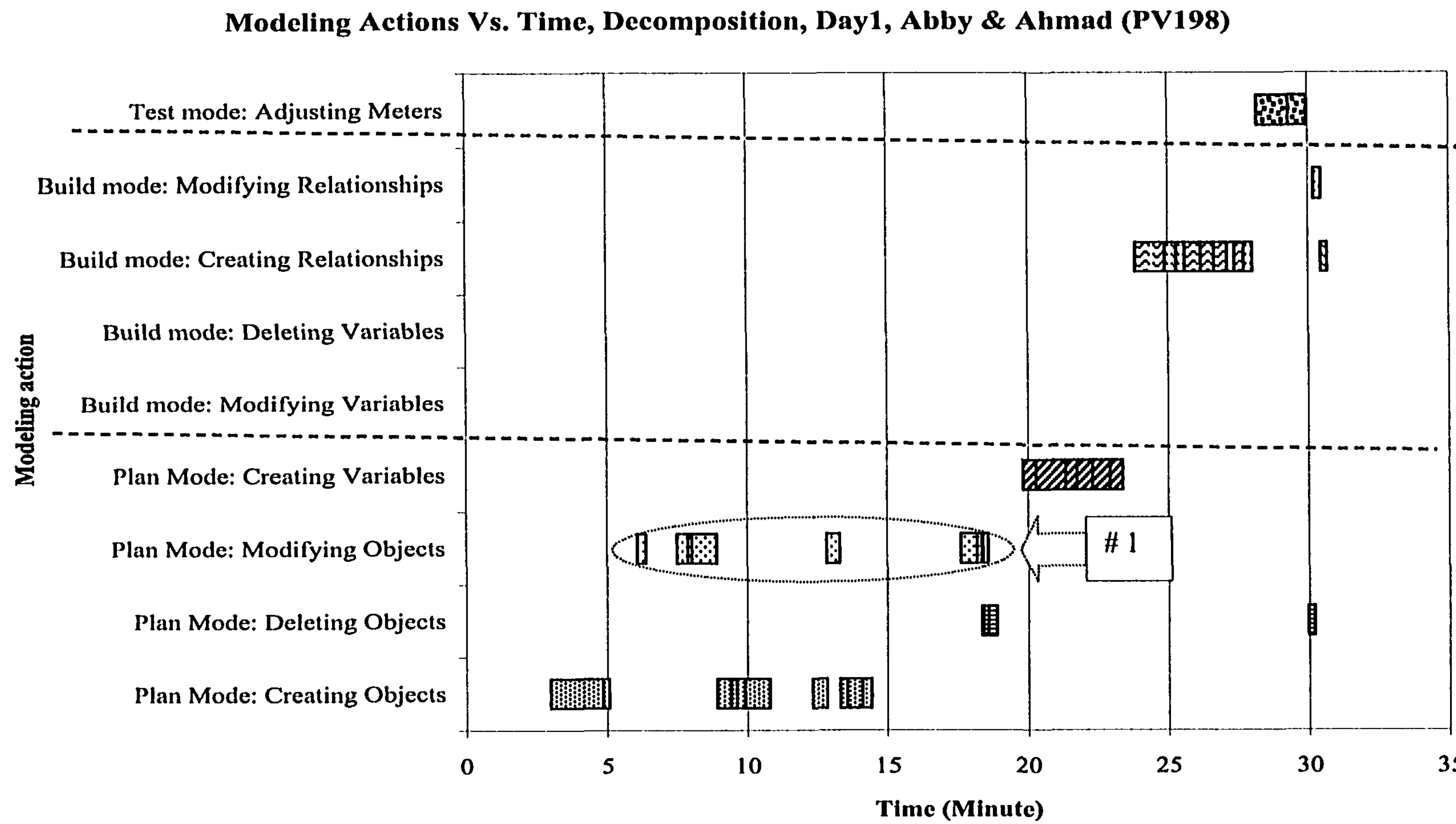


Figure 4.13. Modeling Actions (PV198, Ahmad and Abby)

For students who did not start from the two-column idea, a typical modeling action path looks like the one shown in Figure 4.14, which is clear and concentrated. It seemed that those pairs had gone through the integrated analyzing and synthesizing processes in the same way as the students who started from the two-column idea. However, the abstraction could be skipped by chance, as happened with Jackie and Elias, because they did not find much difference between their two columns.

In summary, analyzing practice is integrated with planning, synthesizing, and even evaluating practices. Analyzing practice seems to be more autonomous and internalized and students no longer asked questions on how to name objects and variables, or fill in the descriptions. Analyzing that is not accompanied with synthesizing and other practices, as in Elias's group, leads to a less sophisticated model.

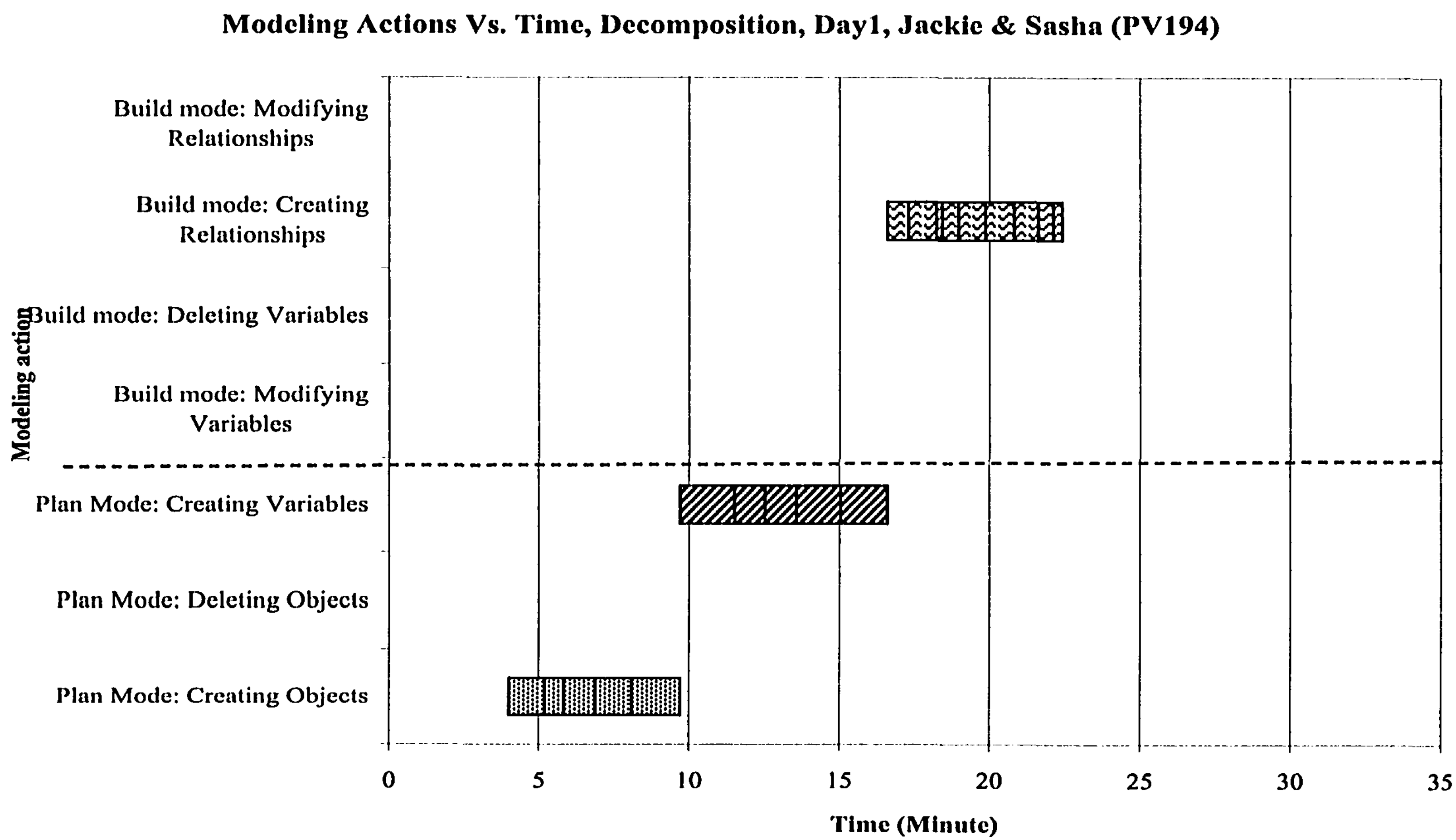


Figure 4.14. Modeling Actions (PV194, Jakie and Sasha)

Synthesizing Practice

Synthesizing practice reflects student modeling actions and conversation about how different parts of a model represent its driving question or focus. It seemed that more synthesizing practices happened at the planning stage and in terms of the influence of the independent and dependent variables. For example, PV191, 1233, although it was implicit, Charles seemed to think about using one independent variable to affect other variables. Elias also kept the idea of independent variable vs. dependent variable in mind, and he decided to have *worm* as the independent variable at an earlier stage (PV195, 0507). Other students also went through such a synthesizing process, with independent variables such as *temperature* and *water* finally emerging.

Synthesizing seemed to be difficult when students needed to make an abstraction of their investigation in order to represent an idea. Visualization of a model seemed to help in synthesizing. As shown in Figure 4.15, Cathy and Simon started from the idea of two columns representing towers of different temperatures—a cold column and a warm column. Those were the two icons that had relationships to the variable on the top: temperature. Then they created decomposition variables for the cold column and warm column respectively. However, as the following episode shows, Simon realized the problem of it being redundant to have two towers representing the temperature change as well as decomposition (PV192, 2951, Lines 1-9).

----------Build mode
1 (PV192) 2951 Students look at the map and try to create more relationships.
2 Simon: oh, I think we are wrong.
3 We mess it up so bad.
4 We are supposed going from here [temperature] to...
5 oh, we really mess it up so bad and it's not even funny any more.
6 Simon makes a relationship from heat of hot column to decomposition.

7 Cathy: How does the heat affect decomposition?
8 Bell rings.
9 Simon: I think we need to start it all over.

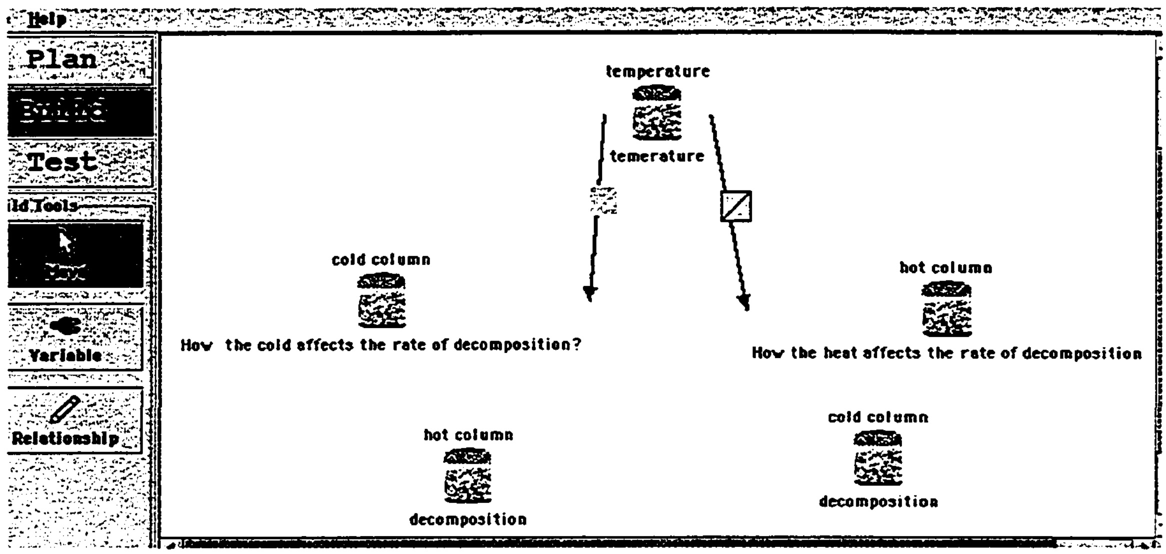


Figure 4.15. Replicated Intermediate Model from the Process Video of Cathy and Simon: Decomposition (PV192, 2951)

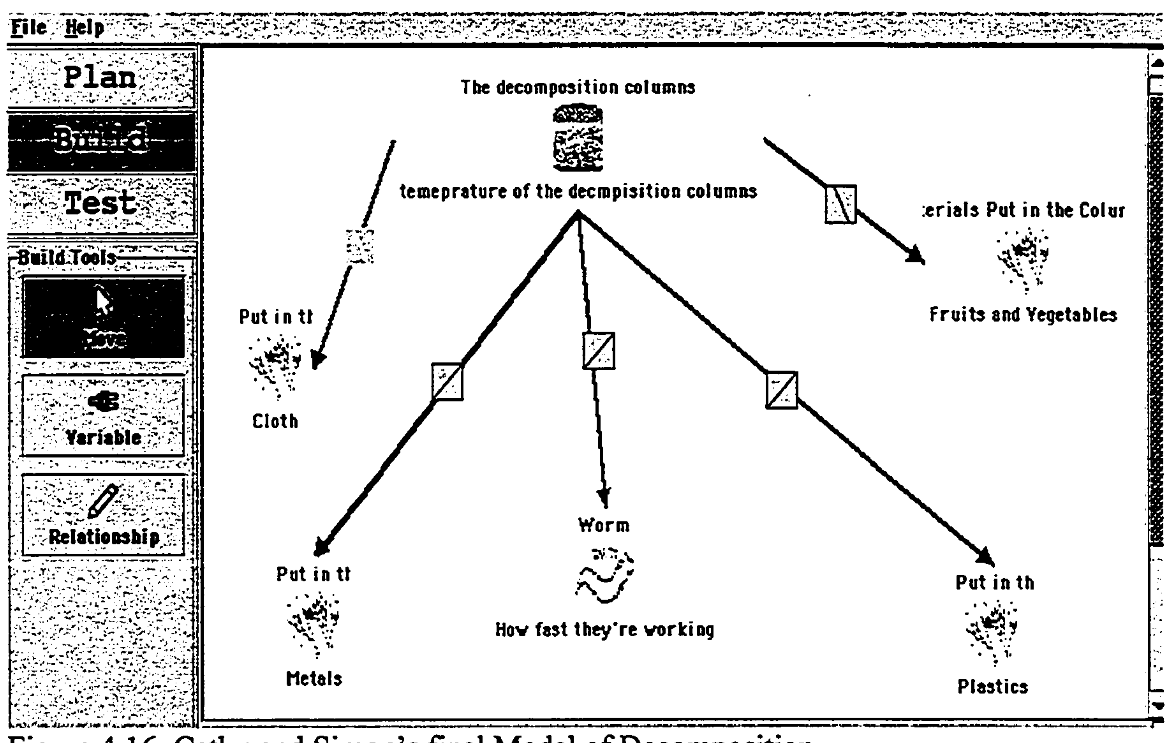


Figure 4.16. Cathy and Simon's final Model of Decomposition

On the next day, Simon seemed to forget his idea so they still worked on the two-column idea. When they were not able to create a relationship that made the amount of plastics remain the same while the temperature of the cold column increased, Simon started thinking again about the idea that had come to mind the day before (PV201, 3000, Lines 5-7). They then deleted one of the columns and made *temperature* a variable of the object—THE DECOMPOSITION COLUMNS as shown on the very top of their final model (Figure 4.16). This example shows that synthesizing took time. Until students had enough information and could pull the information together (using visualization of the model in this case), it was very difficult for them to make the abstraction.

-----------Build mode
1 (PV201) 3000...
2 Students click on the temperature of cold column.
3 Simon: we are gonna messing this thing.
4 Maybe we should make column or something and
5 under the column there is a variable like temperature.
6 Maybe we should change this.

In summary, synthesizing with regarding to organizing and accommodating new concepts seems to be a difficult process. Creating a model to be able to visualize student thinking seems to be very helpful for students in making the abstraction in order to represent a phenomenon. Real experience and using resources seem to make the synthesizing practice more meaningful. Once students have completed the synthesizing process with revised and improved models, they could have learned conceptually.

Evaluating Practice

Evaluating practice reflects student modeling actions and conversation when making judgment on a model's quality using certain criteria. A significant number of revisions happened before students tested their models. Because student modeling practices became more integrated, students could evaluate their model without looking at test results. Since practices became more integrated and students also demonstrated the ability to predict the behavior of their models in some cases, it seems to make sense that students demonstrated evaluating practice before testing. The following chart of modeling practices of student pair Alisa and Charles on Day 2 (Figure 4.17) shows that there were frequent discussions about goals, objects, variables and relationships (#1); revisions of the model (#2); and teacher interventions (#3) before testing (#4) (PV200). The students modified their model before they tested it. They seemed to be able to evaluate the model and were aware of what needed to be done to ensure the quality of the model without having to look at test results. The changes might indicate that students had grown conceptually and thus were able to consider the model more systematically and holistically.

Students created their models more meaningfully because they articulated more when they were testing the model. It became more obvious that they used their investigation as a criterion to evaluate their models. For example, Abby and Ahmad were confused by the fact that some relationships made sense while the overall effect disagreed with the results of an experiment (PV207, 0619, Lines 6-7). Abby even suspected that their experiment was wrong when its results disagreed with their test (Lines 23-24). Actually, this was one of the only two cases across the six pairs over the three cycles in which a model had relationships that affected one variable in different directions. Unless students thought about the model as a whole system and highlighted the more important variable, they would not expect such difficulty. This example also shows that students were used to reading graphs to interpret test results, which also demonstrated progress in learning.

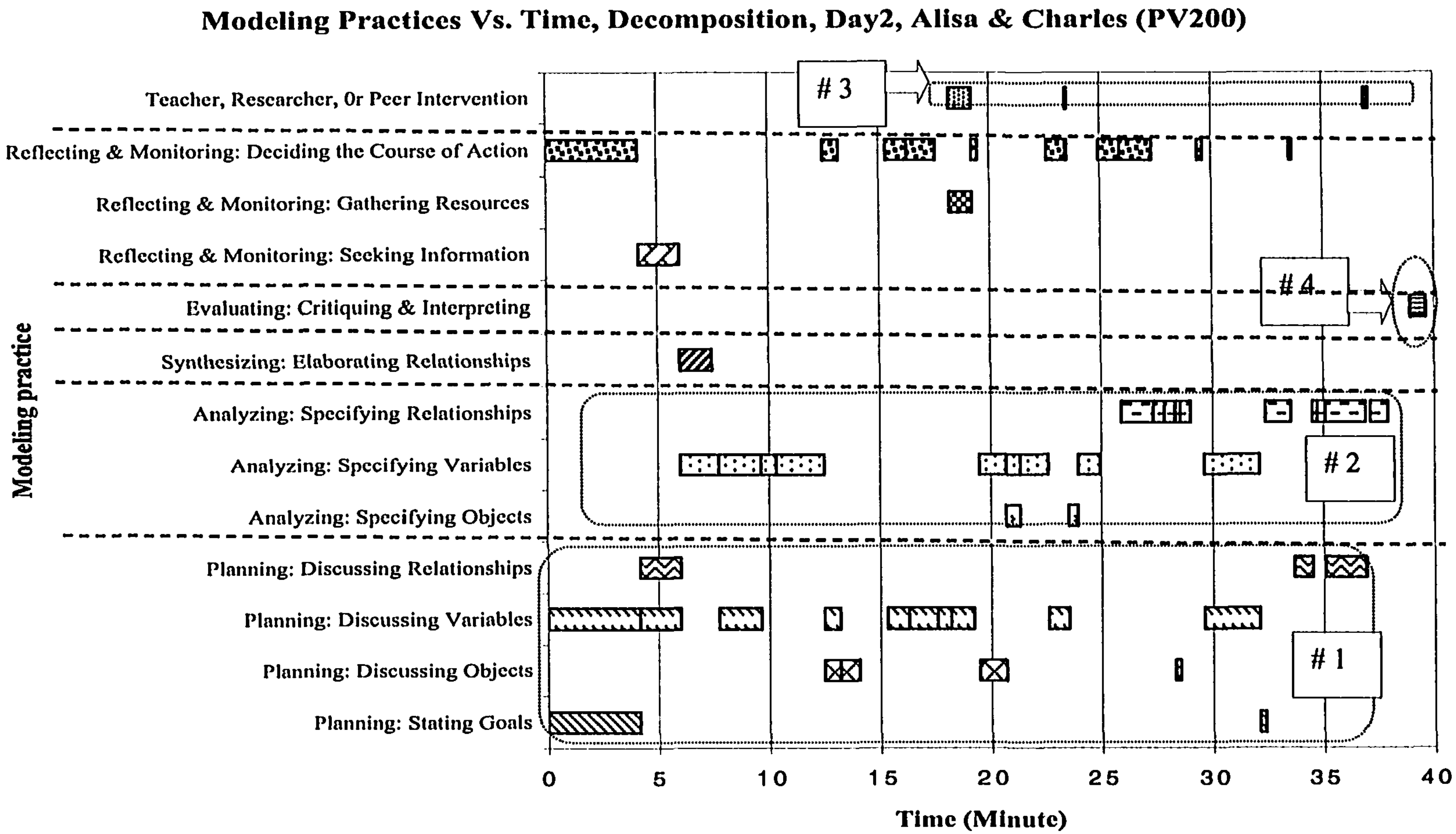


Figure 4.17. Modeling Practice: Decomposition (Alisa and Charles, PV200)

---------Test mode
(PV207) 0619 Students open the meters, graphs and test the model again.
Abby: I think it works. The graph works.
This is probably the third times (of test?).
(Abby is a bit anxious to get things done.)
Ahmad: let's try it one more time.
I do not understand why it (decomposition) goes up when
the temperature goes down.
Abby: because that's...temperature goes down, worms go up,
moisture goes up so that it (decomposition) should goes up.
[Some incorrect embedded relationship here, e.g.
worms like warm, temperature goes up, moisture goes low.]
Ahmad: I understand, but temperature is supposed to increases decomposition.
[Direct relationship vs. indirect relationship]
Abby: Don't worms go underground when it is cool.
Ahmad: yeah.
Abby: So since they like it to be cool so that makes decomposition to be more?
Ahmad: yeah, but...
Abby: see, then our graph works.
Ahmad: but it still doesn't make sense.
Abby: (raises her voice) it works!!
Ahmad: ...but this graph does not agree with our experiment.
The higher the temperature, the (more decomposition).
Abby: we need help!...It works,
...our experiment did not make sense.
Ahmad still thinks it does not make sense...

In summary, evaluating started earlier than testing when students understood how the modeling program worked. Students seemed to use visualization of the model layout to help in planning, analyzing, synthesizing, and evaluating. It seemed that the model made more sense when students used their investigation as a criterion in the evaluation of their models.

Publicizing Practice

Publicizing practice reflects student modeling actions and conversation when presenting their model to others and their class. The need for presenting their models definitely raised student awareness of progress. At different times, all student pairs showed that they recognized the need for presenting and felt the time pressure. For example, at the beginning of Day 2, Jackie told Sasha that they were special, probably because they finished their model on Day 1. When teacher Carol asked whether they were ready for presentation, Jackie answered proudly "we are ready" and she was laughing and singing (PV 203, 1015).

The purpose of publicizing as designed was to promote communication among students and allow them to evaluate each other's models. In general, the test results helped students to see whether the models worked as expected. The criteria students used for evaluating a model were not explicit. The teachers provided a critiquing sheet to students, but they did not use it in the right procedure. For example, after presented to the other group, Jackie and Sasha listened to Judy's group's presentation. Jackie and Sasha did not tell and were not asked about their model's driving question until they had to fill in the sheet to give back to their teachers. Jackie asked the other group their driving question (PV203, 1500, Lines 9-10) and told Judy their driving question (Lines 11-13). Students did have the awareness of feedback for revising the model (Line 15) and Jackie was able to provide her feedback for revising the model (Lines 16-17).

(PV203) 1500 Jackie and Sasha are listening to their peers.
A lot clicking.
T says several times to remind the class that one group
should listen to the other group.
The other group is presenting.
They mention water and temperature.
Jackie: good job!! ...What do we write down? Question.
Jackie: ..Julie, it was very good.
What was your question?
Julie: our question was: how does heat affect decomposition?
Jackie: you want to know ours?
Judy: yeah.
Jackie: how does water affect the rate of decomposition?
Jackie is taking the note.

2130 Another boy: Ok, how about criticism?
Jackie: I just want to know how water affects the heat of column1.
That's what I did not understand? My criticism.
Another boy seems to explain it but could not be heard...
Judy seems also defending.
Jackie: ok, ok, also....Something does not need to decompose..
Jackie and Sasha do not ask their peers' opinions.

In summary, publicizing creates a need for students to think over their models in order to be able to present their models to others. Sometimes students might not follow the correct procedures in evaluating a model, as in the case of using the critique sheet. There seems to be a need for making the criteria explicit. For example, it would be helpful to know what makes a variable accurate.

In addition to the above modeling practices, and as done in WQI and WQII, I also looked other dimensions of student learning involved in the modeling practices. Results of the analysis follow.

Metacognition

Students were more aware of what they wanted for their models and why they made the choices. The images seem no longer to be suggestive because students seek images purposefully. As shown in the following episode, Sasha preferred to create an object of water as their first object (PV194, 0400, Line3). Their driving question was "How does water affect decomposition?" Further, although the image they chose seemed to be irrelevant, they used the strategy that Elias's group used-they just names any image as the object they wanted (Lines 3-5).

---------- Plan mode
(PV194) 0400 Jackie: Is that a worm?
(Students are looking at icon palette)
Sasha: yes, it is. We need water.

Jackie drags an image and Students are sure that it is not related to water but they still use the image.

Students also paid attention to their peers' progress. When Sasha mentioned "they" (PV194, 1857, Line 3), he was probably referring to Elias's group. Elias had decided to use all the materials they used for investigating decomposition as "variables".

---------Build mode

(PV194) 1857 Create Relationship: As worms increase, temperature increases a little, has "because statement".

Sasha: See what they did, they put each thing in their column as variables.

Students sought help from the teachers or the researchers when they had questions. Usually, students would tell each other "we need help". The following excerpt shows that Alisa started to feel the need to ask (PV191, 1420, Line 4). She was very serious about the concepts they used. She tried very hard and the teacher and researchers also helped her to understand the difference between "organic" and "biotic" products. This episode also shows that Alisa used resources (Line 1) and Charles was aware of the time they had spent on tasks (Line 10).

----------Plan mode

(PV191) 1420 Alisa seems reading something.

Alisa: hold on. Let's ask questions. Wait, that's right.

Alisa: okay, you know what. A variable for food...

Alisa: wait, we need to ask questions. I am a little bit confused.

Charles: ok, now, I am confused.

Alisa: we probably need to put something in about the food being organic.

Charles: biotic.

Alisa: organic and biotic are the same thing.

Charles: they are not the same word....

You have been doing this for the past 17 minutes.

Almost all groups of students made use of their background information and investigation records. Some groups, like Elias's group, depended a lot on their notebooks.

In general, students made more frequent uses of their notebooks, CompBooks than they did in the water quality unit.

In summary, students are very aware of their progress, especially with regard to the time constraints and the need for presentation. Students actively seek help and make more use of their notebooks and other records as resources. They also pay attention to peer progress.

Content Knowledge

The modeling processes seemed to promote synthesizing and abstraction of the decomposition concepts. For example, representing how temperature, worms, water, light, and so on affect decomposition was a process of synthesizing and abstraction. Students eventually could synthesize the two-tower idea and express the influence of temperature, worms, water, or light using accurate variables. After students had done the synthesizing and abstraction of ideas, modeling became a process of organizing and deepening student understanding of the phenomenon. It seems that making use of student investigation experience for creating a model is an innovative and helpful way for students to learn both content and modeling knowledge, which is partially the nature of science.

Inquiry Experience

As shown in the results of modeling practices, student models were better aligned with their driving question. Since their driving questions were also their questions in their investigations, there was a much better alignment between what students represented in the models and their investigation experiences. Each student had at least one instance of "making connections" to their inquiry experiences. Students Abby and Ahmad had three (the most frequent) instances of making connections to their investigation experiences, and they discussed thoroughly each time. They also checked their original records in order to be specific and accurate (PV198, 2454).

In general, the connections between student data and model resulted in a more accurate model component, such as a variable with an accurate initial value. As shown in the following example, the model seemed to be meaningful to the students because they cited their investigation to support what they built in the model (PV194, 2715, Lines 1-10 and 13-14).

--------------Test mode
1 (PV194) 2715 Sasha starts explaining what happens to teacher when water is
2 changed.
3 Teacher: That is very nice, so what was your question?
4 Jackie: How water affects decomposition.
5 It was not like "how much...It's kind of how fast..."
6 Teacher: Did you notice if rate of decomposition was affected because of water?
7 Jackie: no,...It was just not that big of a difference, because one had 15,
8 another one had 100. A lot of the worms die.
9 But... there were more bacteria or worms in each.
10 Teacher: That works. Wonderful.
11 Jackie: Rewind.
12 Stop Test. Run Test again.
13 Jackie: I think it is cool. it shows what you did.
14 Sasha: yeah.

The following is another example that shows that students made decisions about what to have based on their investigation (PV198, 1333). This pair was one of the four pairs that started from the two-column idea.

----------Plan mode
1 (PV198) 1333 Abby: ok, so...we need to do...why don't we do worms because
2 they were dozen of someone but not the other.
3 New object: WORM COLUMN1, Normal, Description: (cannot be seen)
4 Abby: just do column1.
5 It seems that Ahmad is typing and Abby is holding the mouse.

The following excerpt shows that although students had observed the phenomenon and collected data, it probably was more complicated than they had discussed. According to them, *worms* affected the decomposition of *socks*. With the increase in decomposition, socks also increased "by a little (PV195, 2008)." However, students did not explain why the socks became bigger, that is, how worms had affected the decomposition of the socks. Basically, they needed to explain what was a sign showing that decomposition had happened.

--------------Build mode
(PV195) 2008 Elias: affect the sock guys.
Does it affect socks? Yes. More and more?
Shaw: a little.
Elias: that' s much more than the pop tab.
Shaw: so?
Elias: a lot.
Shaw: yeah, it does get a lot bigger, doesn't it?
Elias: yeah, it weighs a lot more.
Create Relationship - as DECOMP increases, SOCKS increases by a little.

In summary, besides a better alignment between the driving questions and the content of the models, there was also a better alignment between student investigation experience and student models. One reason for the change might be that the teachers asked students to use their investigation data to support their claims. Furthermore, student models had the same driving questions as those of their investigations. Students might have felt the need to rely on their inquiry experience in order to be more purposeful when they conducting their investigation.

<u>Modeling Knowledge</u>

Three aspects of modeling knowledge were identified in the literature. First, whether students mentioned the purpose of modeling; second, whether students understood how to name an object and a variable, and fill in descriptions and "because statements"; and third, whether students understood how to evaluate a model.

There was no evidence showing whether students understood or did not understand the purpose of models and modeling. Most students seemed to be able to create accurate object and variable names and provide reasonable descriptions. However, Elias' group did not name the variables and did not provide "because statements" for the relationships they created. One reason might be that students were under time pressure. For groups that had the same object and its variable names, such as Abby and Don, and Elias' group, the variable names were not obviously measurable traits of the objects, although most of them still made sense. For example, in a less rigorous sense, moisture and worms could still be interpreted in the sense of *how much moisture* and *the number of worms* .

It was also not clear what criteria students used to evaluate a model. Collectively, it seemed that students had an expectation of how variables affected each other. When they concluded "the model works", it usually meant that the model worked the way they expected. Some cases showed that students also used the results of their investigation as a criterion in evaluating a model. The following episode shows that Ahmad insisted that there was something wrong because the test result did not match their investigation result (PV207, 0619, Lines 4-5). Abby even suspected that their investigation had a problem (Line 6). Finally they both agreed that they needed help (Line 9).

(PV207) 0619 Abby: see, then our graph works.
Ahmad: but it still doesn't make sense.
Abby: (raises her voice) it works!!
Ahmad: ...but this graph does not agree with our experiment.
The higher the temperature, the (more decomposition).
Abby: we need help!...It works, ...our experiment did not make sense.

Ahmad still thinks it does not make sense because the results do not match their
Investigation.
They both agree that they need help.

Elena seemed to be new to Model-It, she told the teacher that she did not understand what they were doing, but after the teacher explained (PV197, 0720, Lines 4-14), she seemed to do well with her team member and contributed a lot to their model.

--------Plan mode
(PV197) 0720 Nathan keeps typing the description.
Elena: (hesitantly) Ms. Gleason,
I do not know what we are doing.
Teacher: You are making a model about decomposition?
Elena: yeah.
Teacher: so what things affect decomposition?
Elena: like moisture…stuffs
Teacher: You need to think about all the variables that you have.
So what is your driving question.
Elena: are you saying the class driving question or group?
Teacher: you said you have good data,
so you need to take a question based on your variables.
Why water, temperature, moisture or something affect decomposition.
You need make all the statements based on your data.

In summary, students demonstrated improvement in their modeling knowledge because they were fluent in creating and evaluating the models. When a teacher or a researcher is involved and they provide feedback or explanation in terms of modeling knowledge, students are more likely to be able to improve their understanding.

Collaboration

Since the target students were either swapped or changed, all target students who remained in the decomposition unit had new partners. Students seemed to have good rapport because there was no dictating or argument about the task allocation. None of the students really dominated or did not listen to their partners.

Even with group member who did not participate much, other group members were able to work with them in a harmonious manner. For example, for one of the two three-student groups, Matt in Nathan's group did not talk much. Nathan tried several times to engage Matt by encouraging him to wire the mic and talk. The following episode shows how Nathan tried to involve Matt (PV197, 1443, Lines 2-8).

--------Build mode
1 (PV197) 1443 Elena: Ok. Uh...what do you think?
2 Elena is checking a piece of paper (according to the sound)
3 Nathan: Matt, do you want to take the mic...
4 What are you looking for?
5 Elena: I am looking...
6 Nathan: how about the worms, the worms affect decomposition,
7 Don't you think so, Matt?

In a later episode Matt said he was afraid of the mic(rophone) (PV197, 2042). In another episode, it seemed that he was very aware of being recorded (PV206, 2330). In contrast, Elena was a new partner and probably new to modeling, but participated actively and seemed to be able to learn because she engaged in meaningful conversation with Nathan.

Zech in Elias's group did not talk much for unknown reasons. He contributed the important idea of putting the independent variable *worms* in the middle and putting all the dependent variables around it to form a circle on the model layout (PV195, 1831), and participated in presentations to other groups at the end (PV204, 2345). Otherwise, it was very hard to feel his existence from the process videos. Shaw was largely excluded by Lisa in the WQ unit. In Elias's decomposition group, he was able to contribute his ideas to the model and usually Elias accepted the suggestions.

The rest of the target student pairs worked closely with both students contributing ideas to the model. Students also listened to each other and were responsive to each other's opinions. For example, Jackie became less dominant and more considerate when talking to Sasha. She seemed to be more aware of Sasha's opinions and was very responsive. It seemed that students had fostered a good habit of collaborating. On the other hand, as shown in some exemplar episodes, it seemed that even if students did not talk explicitly, there was evidence that students were aware of the need for presentation and felt the time pressure. This could also be why students listened to each other and tried to create a good model in a short period of time.

In summary, students demonstrated a better habit of collaborating with each other. In general, the communication within student pairs or groups is natural, rich and productive.

Changes in Modeling Practices (Water Quality to Decomposition)

Students are less dependent on the scaffolding. For example, the images seemed to be no longer suggestive. Elias told the essence of having those images (PV195, Line 5).

----------- PLAN

1 (PV195) 0330 Elias points to the image palette.

2 Elias: is there different something?

3 Another S drags an image but dismisses it.

4 Elias: It doesn't matter; just have a label so that we will know.

Students seemed to think about variables first when thinking about the model. Abby and Ahmad, and Nathan's group gave all the variables the same names as the objects. Elias's group did not even have variable names because they planned to have all the materials as dependent variables. However, they had to create objects first because the program was set up this way (PV195, 1006). Although there was a little bit of difference between the object and variable names for Jackie and Sasha's model, they were in essence the same things because each object only had one variable.

In general, students worked more efficiently in this unit. Most students finished their model in one class period. Students were purposeful and the models were meaningful to them.

At student initial modeling, they usually focused on "if their models work" in terms of how one variable affected another by looking at the meters and graphs in test mode. Later on, they were able to conceptually evaluate the model in terms of their purposes when they considered what to build in their model. They considered whether a variable overlaps with another variable, whether they had chosen something made sense, and whether something fit the results of their investigation. This was especially typical in the decomposition unit because students' observations were more focused than in the water quality unit. There is a much closer connection between the model and their investigation. Students use their investigation to support their decisions and make sense of their models. Publicizing among peers might need closer supervision with more explicit criteria for evaluation. Students might also need to get use to a norm for critiquing.

In terms of student development of metacognition, students showed self-regulatory skills in WQII and the decomposition unit. For example, student Abby was not happy with their progress in WQII for a lack of modeling knowledge. Her partner Don encouraged her by saying that they were making progress, but Abby said that they were making progress "slowly" (PV181, 0311). Another example was about Elias' group. They did not know what to do at the beginning of the modeling cycle of decomposition because they were working on a new subject domain. Elias encouraged Shaw to propose some ideas on what to build in their mode. Elias suggested that it would be the same as they did in water quality unit. Shaw, however, made an excuse by saying that they were dealing with different subject matter (PV195, 0507). This seemed to show that Shaw was aware of his limited understanding of the new subject domain. At least, he was not willing to try to use what he learned previously on new situation when they were creating a model of different subject domain. Elias was forced to move forward without any input from his peers, later he said "We are going to flunk this, we deserve to flunk this...(PV195, 1416)." This shows that Elias was also aware of what he knew and able to do for the model. Further, most students organize their variables and relationships with patterns highlighting the central variables. They were able to plan their models more efficiently and purposefully; this seemed to be improvement of self-regulatory skills.

Students demonstrated better rapport when they formed new pairs or groups. They also shared tasks well. They basically shared their ideas with partners and worked efficiently. Therefore, students also demonstrate better collaboration across the six pairs.

How the Learning Environment Facilitates Modeling Practices

For the so-called "design-based" research, the purpose was to characterize a learning environment that could promote student learning. Therefore, the major aspects of the learning environment need to be addressed in detail in order to evaluate the effectiveness of the design effort as well as student learning. The data showed that the following aspects in the learning environment seemed to be critical in promoting student learning through computer-based modeling practices.

Curricula and Student Inquiry Experiences

The project-based approach provided rich background information and first-hand experiences that were potentially useful for students in creating their models. Modeling was designed for students to demonstrate their understanding and build deeper understanding by discussing and elaborating their ideas.

Before student investigations, the teachers provided guidelines for students to search background information in the library or through the Internet. The teachers also provided benchmark lessons to lay a foundation for student understanding of water quality (water quality unit) and decomposition (decomposition unit). Appendices A and B show the concept maps of the two curricula. Appendix C is an exemplar guideline for students to search background information. Teachers also examined and scored student CompBooks in which students were supposed to write their search results, investigation records, analysis and conclusions.

Both teachers encouraged students to use their notebooks, CompBooks, (Composition books) or booklets for more ideas. Notebooks were used to take notes during classes. Students used a CompBook or booklet to manage and record their inquiry projects. A booklet usually included background information, journals of their investigation, data collected, data analysis, and reports. In class I, it was very obvious that the teacher strongly encouraged students to use their notebooks and booklets as resources because teacher Alice reminded students at least four times during Day 2 and Day 3. She even used a role model to remind students. For example, on Day 4, she announced to the class "oh, Shirley is getting our science book out. Yes! (PV152, 0311)." However, some students seemed not to be used to using the resources. Another student pair, Simon and

Charles, did not use their booklets until a researcher wanted to borrow it on Day 4 (PV151, 1630).

In summary, student notebooks and investigation records become important resources for students in gathering ideas for their models. However, as some examples in the previous text showed, there is still a need for students to foster the habit of using their investigation data to support their decision-making. On the other hand, students do show an increased use of the inquiry experience, especially in the decomposition unit when there was a much closer alignment between student models and their investigation experience.

Modeling Program and Software Scaffolding

The modeling software Model-It seemed to be central in initiating and promoting modeling practices. Scaffolds built in the Modeling software seemed to facilitate analyzing, synthesizing, evaluating, and other modeling practices. If students followed the requirements of the program that tries to enable them to perform and think with all the modeling actions shown in Appendix A, then they were able to perform these practices. However, the practices might not be meaningful to some students. For example, our transcripts showed that students frequently asked questions like "What should be in the name of a variable?" " Why does the 'degree of change' matters for relationships?" When the modeling practices became more meaningful to students, they could have become more purposeful with their modeling practices. When students were planning their model, instead of thinking what objects and variables they would prefer to use, they might have thought about why the object or variable was necessary with regard to their focus and the relationships they intended to build. The modeling practices, therefore, became more internalized, automatic, and purposeful after students understood models, modeling, and how to create models using Model-It. For example, Cathy seemed to have awareness, or was purposeful even at the very beginning of their initial modeling cycle, as shown below (PV134). She questioned but realized that factory could contribute to thermal pollution, which was the focus of their model [Lines 5-7].

(PV134) 0236 Students try to find a new icon to create an object.
Cathy: (Asks a researcher) how do you find..uh...oh, new object.
The researcher tells them.
Students click on new object and open the picture folder.
Shirley: oh, factory.
Cathy: wait, but how factory affects thermal pollution?
Oh, yeah, factory, factory.
Students select factory picture from folder, create a new object:
factory, normal, description:
there is a factory that dumps hot water used for cooling
purposes into the stream.

Appendix A shows the step by step operations for modeling actions. First, students were required to choose an image in order to create an object. The image could be used either as a normal or background image. The images actually contextualized student models with something that was familiar to students and made sense to them. Students also assigned meaning to the images. For example, on Day 2, when Shirley and Cathy wanted to find an image for ROAD in terms of the impact of cars on water quality, they only found a mountain image, which was the closest to what they wanted. They then named it MOUNTAIN-SAID ROAD instead of just ROAD. On Day 2, another pair, Jackie and Elias, in class II, looked at the images. Elias said that he thought the HOUSE image looked like a condo, so students made the initial value of the variable HOUSE: *number of building* as *3*. The teachers chose the images that were available in the program. Some students asked teachers or researchers to help in order to find a specific image to fit their needs. For example, Charles and Simon had some basic ideas about the model, so they looked for images purposely. However, there were many cases in which students used the image palette for ideas about what they were going to build. For example, Abby and Don used up all the images on the image palette and created 9 objects and a complex model, but it did not make much sense to them (Figure 4.3). They had to abandon the model and create a new model in just 18 minutes, and then it made sense to them after Abby decided the driving question at the end of Day 4 (Figure 4.4). Therefore, it seemed there were two sides of the impact of the images. On one hand, they helped students to express their ideas. On the other hand, they were suggestive so that students might just take advantage of them without further thinking about what kind of model they were supposed to build. Although they were able to create a model, the model might not make much sense to them, especially in the very beginning.

As later evidence showed, students seemed to become more automatic in using the scaffolds to create objects, variables, and relationships. They could even evaluate the models before they went to test because they could predict models' behaviors after they understood how the program worked. The images no longer seemed to be suggestive because students sought images purposefully or could assign meanings to blank images if they were not able to find appropriate images.

In summary, the modeling program becomes critical for students to access to the modeling practices that science educators promoted. Over time, the modeling practices become more purposeful and meaningful to students. With an increasing understanding of the program, especially conceptual understandings of modeling, students are able to perform those modeling practices without necessarily being facilitated by the scaffolds in the program. This change is certainly desirable to science educators and researchers.

Importance of Teachers and Researchers in Shaping Student Modeling Practices

As researchers were part of the research project, our presence in the classrooms had some influence, although we tried to minimize our interruption of student learning. The positive side was that students also sought help from the researchers for technical issues of the program and even content issues. Therefore, researchers became a resource for students learning. As some examples have shown, students also kept an eye on their peers. Knowledge and ideas diffused through teacher instruction, group meetings with students who had the same driving question, and class or group presentations. Students could very easily move around in the classrooms to talk to their peers other than their partners. Pairing or grouping to form a learning community provided the opportunity for students to communicate to each other. Students were also able to search the Internet at any time. All of these became important resources in promoting student learning, and it seemed that students took advantage of them to make their modeling practices more efficient, purposeful, and meaningful.

Teachers played the pivotal role in supporting student learning in addition to the people mentioned above. The following sections demonstrated how the teachers facilitated student modeling practices.

First, teachers monitor student modeling processes, such as reminding to save, switching the roles of typer and mouser, encouraging the use of notebooks as a resource, and arranging presentations. Teacher intervention seemed to shape the course of actions (e.g. "save"; "today's task is..." for stating goals) and conceptual understanding of modeling and content knowledge. Teachers usually worked in a similar way because they prepared their curricula together and shared their resources and materials. Basically they had the same schedule with the course progress. However, teacher Alice changed her mind and decided to introduce how to use Model-It in one class. Therefore, some students were able to test their model on Day 2, such as Charles and Simon. On Day 3, teacher Alice provided a checklist on how to exam and evaluate models by students themselves. Although students went through the checklist fast (Charles and Simon spent one minute twenty seconds, and Cathy and Shirley spent one minute) and they did the checking somewhat superficially, the checklist still seemed to be helpful to Charles and Simon because the questions seemed to probe them to reflect on their model (PV142, 0358).

Teacher Carol seemed to stick to the original plan because science for some students in her classes, especially class II, was not their strongest area. Therefore, Carol taught her students to build objects and variables using plan mode on Day 1, and she taught students to use build mode on Day 2. Since students did not have the whole picture of how the model works, they had difficulties with some tasks, such as deleting a variable. On Day 2, Lisa had to delete two objects although she only wanted to delete the variables that were attached to the objects. This caused some confusion because until Day 4, students realized they did not have something for water quality even though the model was about water quality. Students had created the STREAM object for holding water quality but since they deleted it on Day 1, they forgot it.

Second, teachers provided conceptual support when students had questions on content as well as modeling. Students seemed to have more difficulty when they needed to organize and synthesize conceptual understanding based on their specific data in the decomposition unit. Therefore, the teachers provided heavy conceptual scaffolding of content knowledge. As shown in the following episode, teacher Alice helped students to recall their investigation so that they could pull things together to create a meaningful model. This was not because students did not have the knowledge. Without an opportunity such as modeling, student knowledge seemed to be static. Students were struggling with how to create the model before the teacher's intervention.

----------Plan mode
1 (PV200) 0559 New variable: paper, the amount of decomposition potential,
2 range: fully/partial/none
3 Teacher: Are you at all putting in objects that affect decomposition?
4 Like what are things that we need for decomposition?
5 Alisa: we have decomposers as an object.
6 Teacher: what are those decomposers' needs?
7 What do we have to do everyday?
8 Charles: air.
9 Alisa: oxygen.
11 Teacher: so you poked holes make sure there is oxygen.
12 What else did you do?
13 Charles: water.
14 Alisa: oh, yeah, water.
15 Teacher: so somewhere on your model, there should be what these needs are.

Third, the teachers themselves were role models in making connections between what students were supposed to learn and what happened in the real world. The following episode iss an example showing how teacher Alice did this. This news was very relevant to what students were learning (PV185, 0530, Lines 2-4). Although Shirley also heard the news (Line 5), she did not know what she could do about it. However, the teacher's announcement at least probed students to think about an issue like this in terms of what they have learned in class.

1 (PV185) 0530 The teacher talks to the class:
2 This morning on the way over I heard on the radio…

"...In Michigan the legislators are trying to put 10 cents for deposit,
because now they are adding SIX MILLION TONS of trash to the river.
Shirley: yeah, also I heard there is lead in Detroit water.
Teacher: so what they are going to do.
Shirley: I do not know.

It seemed that most students followed the teachers' instruction closely. Simon was a salient example. He always followed the teacher closely and he seemed to be able to make good progress in learning both content knowledge and modeling knowledge. The following is an example showing how he used the teacher's instruction to "decide the course of action (PV169, 2155)".

---------Build mode
(PV169) 2155 Charles: what did you say people affect turbidity?
Simon: we have to test it.
She (the teacher) said we have to test it after we do a few
to make sure they are right.

In summary, teachers, researchers, and peers become very import resources in the purposefully designed learning environment. As the examples have shown, teachers play pivotal roles in facilitating student modeling practices, using the modeling software and collaboration in order to improve student conceptual understanding of content as well as modeling.

<u>Collaboration</u>

In general, there seem to be three types of collaboration across the six pairs over the three modeling cycles. In the first type, there is good rapport and full communication. Exemplar cases include those of Charles and Simon, Abby and Don, and Kelly and Nathan in water quality unit; and student pairs other than Elias and Nathan's groups in the decomposition unit.

In the second type, there is good rapport, one dominating person in a pair or group, and less communication. This type of collaboration is exhibited by Jackie and Elias, and Cathy and Shirley in the water quality unit and Elias and Nathan's group in the decomposition unit. Since students in a pair or group kept some independence, they might not have good shared understanding. Cathy and Shirley showed their disagreement during their presentation. Therefore, collaboration in this case might be superficial. Students might not fully share their understanding, but just "worked together".

In the third type, there is a lack of rapport and respect, and thus good communication. This is the case of Lisa and Shaw in the water quality unit. It was difficult for these students to know each other's thinking. It was hard for them to progress because they did not give each other feedback. For Lisa and Shaw, deletion and modification happened because they could not communicate their ideas to each other and then did not realize the flaws of the model until the teacher intervened. Their understanding seemed to remain the same without feedback.

In summary, good collaboration seems to start with good rapport. When students treat each other in a respectful way, communication and sharing occur naturally and fully. Collaboration is also a process of learning. This could be why all student pairs collaborated better during the decomposition unit, especially in the case of Jackie. She became less dominant and more considerate when talking to Sasha during the decomposition unit. The need for publicizing also promotes collaboration because students need to share their understanding with others.

Conclusions

In this part, I summarize findings and make conclusions based on the results from the three modeling cycles (i.e. WQI, WQII and the decomposition unit). The conclusions are arranged in the order of the research questions that were asked.

Initial Modeling Practices

The discussion of student modeling practices during their initial modeling answers the first research question. First, the computer-based modeling program allows middle school science students to perform a variety of modeling practices. As the ER charts show, the practices did not happen randomly. They are purposefully scaffolded by the modeling program.

Second, other dimensions of learning that are involved in student modeling practices seem to influence the effectiveness of student modeling practices. The data shows that the other dimensions of student learning were affected and affect the efficiency, meaningfulness, and purposefulness of student modeling practices. Those dimensions include student investigation experiences, content knowledge, modeling knowledge, metacognition, and collaboration.

Third, for this "design-based" research, the innovative classroom environment seem to be effective in promoting student modeling practices, although some minor revisions are needed. The major elements in the learning environment are: a) the modeling software, b) student notebook and investigation records and other resources, and c) teachers and researchers as more knowledgeable others. The way the classrooms are arranged also encourages students to communicate and collaborate.

Changes in Modeling Practices over time

The changes of student modeling practices provide answers to the second research question. In this section, I first summarize the general tendency of changes that occurred in both WQII and the decomposition unit. I then discuss some unique changes in the decomposition unit because students formed new pairs and worked on a different subject domain.

The following changes occurred in WQII and the decomposition unit, compared to student modeling practices in WQI. First, when students became more familiar with how the modeling program works, they become less dependent on some of the scaffolds of the modeling program. For example, in WQI, some students used an image-driven process to decide what objects they needed to have in their model, later, however, they learned to use blank icons to represent their objects if there were no satisfactory images.

More interestingly, students seemed to think about their variables first; then the object editor seemed to become redundant and some students used the same object names as the variable names. Students also tended to consider their model holistically by referring to the relevance of each model component to their driving questions or foci before they created the model.

Second, in relation to the above change, student modeling practices seem to be more integrated. It is difficult to distinguish whether an episode is analyzing, synthesizing, or evaluating because students plan or specify relationships (synthesizing) when they are planning or creating objects and variables (analyzing); they develop ideas of adding, deleting, or modifying objects and variables (analyzing) when they are creating relationships (synthesizing). Students are also able to predict what the model would look like and its behavior as an indication of synthesizing practice.

Third, student modeling practices become more efficient, purposeful, and meaningful over time. Student modeling practices become efficient in terms of the number of objects, variables, and relationships that they are able to create in a certain amount of time, as well as in terms of how sophisticated their models are. Students become more purposeful because they use driving questions as shared foci when deciding what to build in their models. They also tend to make more connections to their investigation experiences, especially in the decomposition unit. Student modeling practices become more meaningful because students provide more rationale for their decisions and they are more purposeful. The practices are also more meaningful because the models become more meaningful to students. Students become clearer and more elaborative when explaining how things affect water quality and how decomposition is affected by temperature, worms, water, light, or other variables.

Lastly, student metacognition also seems to be improved. When students become more purposeful in deciding their courses of actions and specifying model components, it seems to be a sign of improved metecognition. The improved understanding of modeling and how the program works probably helps students monitor their progress. Students also actively seek information and help from the teachers, researchers, or checking their own records on the notebooks, CompBooks, or booklets. They become very aware of the need for presentation so that they pay more attention to the time they spend and the meaningfulness of their models in order to finish their work on time and be able to present their models clearly.

There are two more significant changes, which occurred in the decomposition unit. First, understanding, organizing, and synthesizing new content knowledge takes time and is difficult. Although students did investigation first, they only had totally six weeks to interact with the content knowledge of decomposition comparing to four months interaction with water quality before they started the initial modeling. Further, decomposition is a subject domain that students had less experience comparing to water quality through their daily lives. Therefore, they demonstrated more difficulties when synthesizing and representing the concepts in the decomposition models. Nonetheless, modeling turned out to be a good way to promote the synthesizing of conceptual understanding of subject matter.

Second, overall collaboration improved across the six pairs. Students became more used to talking to each other. They responded to each other in a respectful way. The increased purposefulness of their practices and meaningfulness of the models is also a sign of improved collaboration because the purposefulness and meaningfulness are based on student conversation and communication. All groups became more deliberate when they became more purposeful in creating their models.

In summary, there is evidence showing that the class environment and the modeling program are effective in promoting student learning collaboratively. Students improve both their content knowledge and modeling knowledge through their computer-based modeling practices.

<u>How the Design of the Learning Environment Facilitates Student Modeling Practices</u>

There are a number of ways in which the design of the learning environment facilitated students' modeling practices. First, Model-It makes dynamic modeling accessible to middle school science students, which means students do not have much difficulty using the computer-based modeling tool to create, think of and with, and evaluate models of science phenomena. Middle school students are able to create meaningful and dynamic models of reasonable sophistication and complexity using the modeling software.

Second, the inquiry-based science curricula allow students to engage in learning rich content knowledge and experiences as bases for their computer-based modeling practices. On the other hand, as the data showed, computer-based modeling transforms student content knowledge and experiences into an understanding of scientific phenomena in a systematic and meaningful way, in turn deepening student content knowledge and understanding of their experience.

Third, teachers play pivotal roles in providing guidance for student investigations, searching for background information, and teaching benchmark lessons. During computer-based modeling processes, teachers demonstrated modeling practices as well as using the modeling program, reminding students with issues raised, supervising, and providing conceptual support to students. Therefore, teachers become the major information source and facilitators of student modeling practices.

Fourth, collaboration is critical for students to be able to articulate their thinking and receive feedback, thus co-constructing new knowledge. Over time, some students learn how to treat each other respectfully to create good rapport; they are able to communicate with each other more naturally and effectively.

In the following Chapter five, I discuss the significance of findings of this dissertation and what it means to the field of learning technology and science education.

CHAPTER V

DISCUSSION AND IMPLICATIONS

Following the design-based research approach, this dissertation investigated the development of middle school science student computer-based modeling practices and their change over time, as well as how the classroom learning environment facilitates modeling practices. The dissertation intended to develop a profile of how students create models in a purposefully scaffolded computer-based modeling environment. The findings show that students are able to engage in efficient, purposeful and meaningful modeling practices over time when they are scaffolded by the teachers, the curricula, and the computer-based modeling program. They were also able to make use of and improve their inquiry experiences, content knowledge, modeling knowledge, metacognition, and collaboration. With the characterization of student learning, a detailed analysis of student modeling practices indicates that computer-based modeling can be beneficial for students in improving those understandings. This study provides empirical evidence regarding the value of using computer-based modeling to engage student in modeling practices.

Based on the findings, I discuss implications to illustrate the possible application of the design. The first part discusses the major themes that emerged from the findings. The themes synthesize the findings in relation to the three research questions, and contribute to the field of science education and learning technology. Combining the "lessons learned" (Collins, Joseph, & Bielaczyc, in press) and connections to the literature, I propose some suggestions for modifying the design of the learning environment. Implications are given with suggestions in terms of how the findings might theoretically and practically change science teaching. I then provide a bigger picture of the project and the following work that is expected to occur. At the end of this chapter, I provide possible directions for future research on student learning with computer-based modeling.

Discussion of findings

Theme 1: With Appropriate Scaffolds, Computer-based Modeling Provided Opportunities for Middle School Students to Demonstrate A Variety of Modeling Practices that Are Desired by Science Educators

Science education should prepare students for participating in competent scientific practice. The dissertation work shows that, even at their initial modeling cycle, Model-It allowed students to perform a series of context-based cognitive skills (modeling practices) that are necessary for conducting inquiry in science domains, such as planning, analyzing, explaining, causal reasoning, synthesizing, seeking information, and evaluating a model. Most of the modeling practices are characterized as higher order cognitive skills (Anderson & Krathwohl, 2001; Bloom, Mesia, & Krathwohl, 1964) that have been promoted by science educators and educational researchers (e.g, Kozma, 2000; Zohar & Dori, 2003). The modeling practices demonstrated by students matched those of scientists (e.g. Bowen, Roth, & McGinn, 1999; Latour, 1987). Further, Model-It is intended to help students foster a way of thinking—system thinking, which considers a phenomenon as a system of interrelated variables (Mandinach, 1989; Schecker, 1993). The findings became more evident when students engaged in iterated modeling practices in WQII and the decomposition unit. In the following part of Theme 1, I discuss student initial modeling practices during the WQI session.

Planning is an important part of student inquiry. It is critical in collaborative learning when students create shared goals (Davis, Hawley et al. 1997; Krajcik, Blumenfeld et al., 1998). Consistent with the literature, during student initial planning practices, a lack of driving questions as shared foci brought difficulty to some student pairs in creating their models efficiently. The difficulty might also be due to the high cognitive load of making sense of the subject domain, the use of the program, and the understanding of models and modeling. However, student planning practices improved in WQII and the decomposition unit as shown in Theme 3.

When building a model, students are constructing explanations using what they have known (Edelson, Gordin, & Pea, 1999; Passmore & Stewart, 2002). One way to do this is through analyzing. The data showed that at the beginning of initial modeling, students followed the sequence of the modeling program in deciding a model's components and its details, such as an object and its description. Students were able to create objects, variables, and relationships with limited content knowledge and modeling knowledge during their initial analyzing practice. It was a process of sense making because students did not have the whole picture of their model. The scaffolds, such as the variable editor, became necessary for them to understand what they were supposed to build for a variable. The sequencing of the modeling tasks, such as creating an object first, then its variables, then relationships, thus reduced the cognitive load of students so that student learning from modeling was possible.

Synthesizing is a key part of effective inquiry (Edelson, Gordin, & Pea, 1999; Passmore & Stewart, 2002; Reiser et al., 2001). During WQI, students made use of the visualization of the model layout and the test mode to synthesize the content of the model. The need for presenting their model also prompted them to synthesize their model and forced them to consider a driving question that is in alignment with their model.

Evaluating is important because it is a process of articulating and validating arguments and explanations (Driver, Newton, & Osborne, 2000; Sandoval, 2003). During the initial modeling cycle, testing became a way to facilitate the evaluating practice. However, the criteria that students used to evaluate their model were implicit.

As many have argued (e.g. Latour, 1987; Woolgar, 1988), scientists are involved in frequent communication with their colleagues in the field to make their thinking public. They might present their studies at professional conferences; they communicate with colleagues through correspondences, or even through person-to-person meetings. Therefore, adding this practice to the modeling integrated curricula was very necessary. During WQI, the need for presenting models to classes or teachers motivated students to talk to each other to ensure mutual understanding and assure the quality of the models.

In summary, in Theme 1, I have discussed the importance of the modeling practices and how students performed the practices during their initial modeling cycle. Given the complexity of the modeling practices with different dimensions of learning that are involved, it took time for students to be able to make sense of what they could accomplish with the scaffolds built in the program and provided by the teachers. In

Theme 2, I discuss how the design of the modeling program helps students to perform those practices. In Theme 3, I discuss the changes in student modeling practices and the significance of those changes in relation to the literature.

Theme 2: The Computer Program Made Modeling accessible to Middle School Students

Although creating, evaluating, and revising a model is a complicated process, the modeling program was successful in initiating and facilitating modeling practices as intended. The results suggest that the following software design strategies worked for the middle school students (Metcalf, Krajcik, & Soloway, 2000) and might also be applicable to other educational software designs for middle school students.

First, a good design starts from what students are familiar with. Students bring prior knowledge and experiences to learning situations. The modeling cycles were arranged at the end of student investigations so that they could make use of their inquiry experiences and basic understanding of the subject domains. The images selected situated students in prior inquiry experiences (Brown, Collins, & Duguid, 1989; Lave & Wenger, 1991).

Second, breaking down complex tasks and sequencing the tasks seems to be an effective way to facilitate student modeling practices. As indicated in the literature, tools with a more constrained, streamlined task-oriented approach to organizing content help learners to begin in a new domain meaningfully (Rosson, Carroll, & Bellamy, 1990). Thus, the constrained activity spaces with functional modes seem to prevent learners from being overwhelmed.

Third, hiding the complexity and using natural language ease learning (Collins, 1996). On the relationship editor, instead of writing complex equations, students simply pushed buttons to form relationships using natural language. It made the complex causal reasoning accessible to students so that they were able to focus on the conceptual part of the relationships. The graph that corresponded to a defined relationship provided a real science representation. Combined with the textual representation of the relationship, the multiple representations also enriched student understanding of the relationships of a subject domain.

Lastly, the test mode of meters and dynamic graphical representations provides instant feedback on a model's behavior. Such scientific visualization helps students become reflective (White & Fredricksen, 2000). It also promotes student conversation in order to negotiate and construct scientific understanding (Gordin & Pea 1995).

Overall, Model-It became a cognitive tool (Salomon, Perkins et al. 1991; Roschelle & Teasley 1993) for students to externalize their thinking, manipulate the representations, analyze and synthesize model content, receive visual feedback, and collaborate.

Some revisions also need to occur in order to make better use of the modeling program in the future.

Plan Mode

In order to make planning obvious so that it raises student awareness, a space for students to articulate their driving question and scenario is needed. As the analysis shows, when student efforts were aligned with their shared focus, they became more purposeful in deciding what to include in their model. The model they created was, therefore, more meaningful to all students in the pair or group. This space could be like a memo so that students can come back and check it easily and keep track of their progress. Exemplar phrases on the scaffold might look like: "Our driving question is…"; "We want to describe a phenomenon of…"; "We will have the following objects….Because…"; and so on.

Build Mode

First, as the data showed, students were able to think about cause and effect between variables in an interactive (two-way) manner, which means they realized that things usually affected each other or had an indirect effect through other variables. Therefore, a feedback loop should be allowed in the program.

Second, on the relationship editor, the program currently allows only the independent variable to "increase". It would be better if it also included two other conditions: "decreases" and "remains the same". Also on the relationship editor, the degree of change needs to have an option of "stay the same" because sometimes, with the change of an independent variable, the dependent variable might stay the same. For example, as time increases, the amount of decomposition of metals usually stays the same because they do not decompose. Further, it seemed that the program should allow students themselves to define how a variable changes and the degree of change by themselves in order to accommodate unexpected conditions and provide flexibility to users.

Third, when two or more relationships were affecting one variable from different directions, it might be a good idea to use a prompt to remind students about the situation and allow students to discover the issue so that they could deepen their understanding of a complex phenomenon.

Test Mode

Over time, students were able to predict the model's behavior before running a simulation. To help students to reflect on their model and make the prediction intentionally, it would be helpful to allow students to print the model layouts on Plan and build mode. The program might also need to make the whole model into textual format to show what objects, variables, and relationships students had created and all the details of each of the components. For example, a model in a textual format can show variable names, their initial values, and their descriptions so that it becomes easier for students to think in terms of the whole model. A possible example might look like the replicated models that I created for analyzing the models in Appendix G and H.

<u>Theme 3: Student Modeling Practices Became more Integrated, Meaningful, and Purposeful over time</u>

Even though students were able to perform the modeling actions that reflected the modeling practices, it is a process for students to understand those modeling practices that were scaffolded by the software program and teachers. In the following section, I discuss each of the modeling practices and how they change over time.

Planning Practices

The results show that over time student planning practices changed so that their planning centered around their driving question or foci as shared understandings within student pairs or groups. Planning became more purposeful with increasing student awareness of the procedures and time needed to create a model and the relevance of a model component to what students wanted to portray. According to the literature (Flavell, 1976; White and Fredricksen, 2000), planning is related to student metacognition. The study also supports this point because students became more purposeful in creating various model components over time. Given the fact that student content knowledge and modeling knowledge seemed also to relate to planning practice, the improvement of student metacognition might also be due to their improved content knowledge and modeling knowledge.

Further, in order to expand the scope of peer interaction, During WQII, teacher Alice suggested that three groups shared the same driving question instead of each group having their own driving question that was different from others in WQI. The result showed that students were able to draw on the conceptual resources of other peers who had the same driving questions as theirs. Therefore, this expanded collaboration in planning could enable students to more easily share their ideas with a larger group of peers who have the same focus.

Analyzing Practices

Student analyzing practices became more integrated with other practices over time. For example, students demonstrated synthesizing and evaluating practices while analyzing what to build in a model. This change could be developmental. The integration is necessary for being more experienced modelers (Nersessian 1995).

Students also tended to think about variables first at the very beginning when they created a model. This is more consistent with the way they worked during their investigations and data analysis. This finding is also consistent with the result of a previous study that explored how senior doctoral students used Model-It (Zhang et al., 2002). The doctoral students in that study confused the use of objects and variables because they usually think in terms of variables and relationships when creating a model. Therefore, the change might be a sign of student development in modeling practices. Miller and his colleagues found that when doing computational modeling, pupils aged 11-14 think most naturally in terms of objects and events, not variables (Miller et al., 1993). This can be a reason for the current design of Model-It, which requires students to create objects first. However, this study might challenge or modify Miller and his colleagues' claim. That is, students with empirical inquiry experiences might be able to think about a model in terms of variables and cause and effect relationships without having to refer to specific objects.

Synthesizing Practices

Over time, the data showed that students were able to make connections between variables in terms of their cause and effect relationships without having to refer to the relationship editor or the test mode. This change shows that students faded the scaffolds over time. Further, students could plan the relationships by looking at the model layout with only objects or variables. This might indicate that students learned to synthesize without the scaffolds built into the program. Combining this with the finding that student modeling practices became more integrated over time, it can be concluded that students become more sophisticated when building a model.

Moreover, students seem to be able to recognize without assistance the alignment of their driving questions to their models. They might have developed a way of thinking by considering a phenomenon as a system of interrelated variables (Mandinach, 1989; Schecker, 1993).

Evaluating Practices

Over time, students could make evaluation at any stage of the modeling practices. Students were able to predict their models' behaviors even without running a simulation in test mode. A need for presentation seemed also to motivate students to evaluate their models after the initial modeling cycle. However, it was not clear what criteria students used. Usually they concluded "the model works", which meant the independent variable(s) affected the dependent variable(s) in the way that they expected. When student models were more aligned with their investigation in the decomposition unit, they seemed to use their investigation results as a criterion to evaluate their model.

The test feature only allows students to find out if variables are connected and if the direction of a relationship and its degree of changes is correct by looking at the simulation. It does not help students discover if a variable name and its descriptions made sense. Sometimes students had difficulty discovering anomalies through testing. Students likely need other means of feedback to evaluate their model. With a teacher presence, evaluating during publicizing seems to be a good way for students to receive useful feedback. There also seems to be a need to emphasize the criteria for evaluating a model. Enforcing serious use of the critique sheet might help students learn how to evaluate a model.

Publicizing Practice

Over time, increased elaboration helped students to plan, analyze, synthesize, and evaluate their models, thus better preparing them for the publicizing practice.

Publicizing as a modeling practice also became a pedagogical strategy. It was not only beneficial to students who presented, but also very helpful for students who listened and asked questions to articulate and confirm their own thinking if it was not consistent with other classmates and the teachers.

Theme 4: The Modeling-integrated Curricula Enhanced Student Learning

There were several features of the curricula that might have promoted student modeling practices. First, the project-based design of the student activities encouraged students to engage in inquiry-oriented learning (Krajcik et al., 1998; Novak & Gleason, 2001). The investigations of water quality and decomposition allowed students to obtain rich inquiry experiences and content knowledge. Second, following the project-based science principles, computer-based modeling naturally fit in and became an integrated part of the curricula. Third, the iterated cycles of investigations and modeling provided opportunities for students to synthesize what they had learned and reflect on their experiences. Fourth, learning materials such as textbooks, background information, and class instruction became both material and conceptual resources. Further, the classroom learning environment fostered collaboration as a social resource. Lastly, the curricula integrated student learning of modeling practices, metecogntion, inquiry experience, content knowledge, and modeling knowledge

The five water quality tests connected student learning to the concerns of practicing science. They were adopted from a manual created by scientists who cared about the natural environment and education (Stapp & Mitchell, 1995). Further, the class presentations seemed to be successful in motivating students to articulate and elaborate ideas and receive feedback. Thus, as the research findings showed, inquiry-based science curricula (Krajcik et al., 1998; Novak & Gleason, 2001) could help students to develop inquiry experience and content knowledge, as well as modeling knowledge when doing computer-based modeling.

It was a process for students to create a norm of sharing and critiquing models. At the initial modeling cycle, most of the comments and critiques were from the teachers. This was probably because students were not familiar with critiquing. Over time, students became involved in more critiques and discussions, especially with the teachers' requests for sharing. Some student feedback and critiques really captured the major issue of a model.

On the other hand, critiques among peers without teacher involvement could be superficial. Although the teachers could prepare critique sheets, students might use them differently from the teachers expect. Therefore, there seems to be a need for teachers to enforce the correct procedures in using the critique. There seems also to be a need for emphasizing the evaluating criteria when students present and critique models.

Metacognition

Previous studies (e.g. Duell, 1986) indicated that as children get older they demonstrate more awareness of their thinking processes. In this study, the improvement of student metacognition seems impossible to attribute to student age because the curricula only spanned an 8-month period of time. The results showed that better understanding of the modeling program as well as procedures and content understanding might have raised student awareness of what they needed to do. Model presentation also forced them to monitor their progress closely. The very nature of the design of the learning environment might help improve student metacognition as modeling practices became more meaningful and purposeful.

Students had demonstrated the metacognitive knowledge (e.g. self-knowledge and self-regulatory skills) that was described by White and Frederiksen (1998; 2000). They were aware of what kind of knowledge and expertise they could make use of. They also showed strategies to monitor their progress and sought help. However, it was difficult to find instances showing student self-improvement expertise in terms of how to improve their self-knowledge and self-regulatory skills. This might be an area that can be improved when more attention is paid to this issue in a future revised design.

Another significant finding is that student understandings of content, models and modeling, and metacognition might be related. This result echoes the successful implementation of computer-based modeling with an emphasis on promoting middle school student metacognition (White & Frederiksen, 1998).

Content Knowledge

Previous studies showed that Model-It provided a unique opportunity for students to create "artifacts" that "construct" connections between concepts and reveal, exchange, and modify their understanding about subject matter (Spitulnik et al., 1998; Stratford, 1996). This result of this study confirms the previous findings; it is also similar to that using the GTK modeling program for biology. Modeling in that study also initiated frequent discussion of content knowledge (Stewart et al., 1992).

This dissertation also showed that Model-It provided an opportunity for students to make connections between student investigation experience and their previous knowledge and experience. With frequent discussion of content knowledge and building shared understanding in their models, students developed a deeper understanding of science phenomena, i.e. water quality or decomposition. This result seems to be consistent with other researchers' claims (e.g., Gardner, 1991; Lehrer, 1993).

Considering the difficulty students had when synthesizing concepts and creating models of the decomposition unit, it seemed that the practices are domain-specific (Tabak, Smith, Sandoval, & Reiser, 1996). For the two units of this dissertation study, the science domains are those that tie to water quality and decomposition. The nature of student practices depends on the nature of a specific domain concerning the content knowledge as well as domain knowledge (Bednar, Cunnighham, Duffy, & Perry, 1991).

Inquiry Experiences

Results from science studies suggested that data collection and interpretation of data are central to scientists' daily lives; representations were at the heart of scientific practices (Latour, 1987; Woolgar, 1988). Inquiry experiences are necessary for students to think and build in a model. Modeling becomes a way to synthesize and reflect on student inquiry experience in order to understand science content as well as science as an enterprise (NRC, 1996).

In this dissertation, I defined "inquiry experience" in a narrow sense--the process of designing, carrying out physical investigation, analyzing data, and making conclusion, but did not include modeling processes. The data showed a much closer alignment between student inquiry experiences from their investigations and the content of their models in the decomposition unit probably for the following reasons. First, decomposition is a topic that was less commonly perceived by students in daily life; therefore, they had to depend on their investigation experience. Second, after students went through cycles of creating, testing and publicizing their models of water quality, they became more purposeful in the information they needed. This could be the reason why students made more connections to their investigation experience over time.

Modeling Knowledge

The results of this study showed that Model-It allowed students to learn the basic modeling knowledge, such as "What is a model?" "What is in a model?" "How do you create a model?" and "How to evaluate a model using the test mode?" Over time, students understood and meaningfully used the concepts of objects, independent vs. dependent variables, and cause and effect relationships. They seemed to be able to transfer their modeling knowledge to a new modeling situation (i.e. from subject domain of water quality to decomposition). Allowing students to create their own models had the advantage of student knowing and understanding a model in detail. Students were not only able to create models, but also were able to understand what to include in a model and why to include a model component to serve the purpose of a model (Greeno & Hall 1997). To date, there seems to be few modeling programs that have allowed middle school students to create their own models successfully and meaningfully.

On the other hand, it seemed that students had tremendous difficulty when more than one relationship affected the same variables in opposite directions. This was also important modeling knowledge that students need to learn because of the complexity of the real world. There was a need to remind students when a situation happened so they could highlight the major independent variable(s) to make the effects correctly reflect the real world phenomena. Going through several cycles of model building helped improve student modeling knowledge in terms of how to consider the complexity of natural phenomena.

<u>Theme 5: Teachers Played Pivotal Roles in Facilitating Student Modeling Practices</u>

A teacher can be a cultural mediator between the community of science learners and the community of scientists (Kelly & Green 1998). In this study, teachers modeled the modeling practices, indicated their expectation, posted questions, reminded students to draw on resources, and mediated student modeling practices. The results show that teachers' teaching practices could shape student learning performances and their enactment of modeling practices (Collins, Brown, & Newman, 1989; Krajcik et al., 1998; Perkins, 1996). Given the high demand for teachers' expertise in this type of innovative approach to teaching, research is needed on how teaching practices, teachers' content knowledge, and pedagogical content knowledge influence the enactment of modeling practices.

The teachers who taught in the three classes were two very experienced teachers with research experience. However, computer-based modeling was also new to them. Through working with the researchers and programmer, they learned quickly and used their modeling expertise in their teaching. They also tried different approaches in order to ease student difficulty with the use of the program, content knowledge, and modeling knowledge in a constrained time period. In the initial enactment of the curricula, both teachers introduced the modeling program in one class period. Teacher Carol introduced Model-It according to modes and modeling tasks during this second enactment but the approach brought some difficulty to some students. How to introduce the modeling program and modeling knowledge in a coherent and effective manner seems to be an issue to address.

It was evident that students were able to clarify their thinking when they sought information from the teachers with specific questions. Teachers also intervened to remind students to save, fill in description boxes, share tasks with partners, and draw on resources. When teachers probed students to explain their models, students received usable feedback. This type of teacher intervention led to the revision to student models. However, when a teacher intervention was less specific, such as asking whether students had questions, students did not respond specifically and were less likely to receive new input. Therefore, it seems that probing students to articulate their model or encouraging students to ask questions can be more helpful for students to receive feedback and input.

Further, if the design is intended to be used on a larger scale in schools with a diverse population of teachers and students, more scaffolds might be needed not only for students, but also for teachers who are less experienced and new to modeling. For example, even the two experienced teachers tried to figure out which was the best way to introduce modeling knowledge and the modeling program. Less experienced teachers might need suggestions about how to discover student understanding of models and modeling and how to provide scaffolds to promote understanding.

Theme 6: Effective Collaboration Was very Important for Learning in A Community of Learners

In the study, students seemed to engage more collaboratively over time. Most students were able to use the driving questions as shared foci to plan, analyze, synthesize, and evaluate their models, and move forward. They talked to each other in a respectful and responsive manner. Students in a pair or group took turns typing or operating the mouse. More importantly, students came to consensus on what they wanted to build in models and constructed a shared understanding of the content knowledge and modeling knowledge (Stratford, 1996). This finding agrees with Roschelle (1992) that learning by collaborating is a search for convergence among members of the learning community. On the other hand, disagreement on the interpretation of a same phenomenon between students in a pair or group demonstrates that collaboration might lead to individualistic student thinking. However, this was less common among the six pairs of students over three modeling cycles. It was also evident that some students did not show their disagreement during the modeling processes when they presented to the classes. Therefore, collaboration seemed to lead to both individualistic and convergent solutions.

Theme 7: The Design of the Learning Environment Provided Rich Resources for Facilitating Student Computer-based Modeling Practices

Following the design-based research approach, this study took place in a learning environment with rich resources around the use of the computer-based modeling program. In this learning community, students made use of social, conceptual, and material resources (Roth, 1996). Below I discuss the three types of resources. The Theme presented here also intends to summarize the other six themes that comprise the whole classroom learning environment that fostered student modeling practices. In this environment, as Penner (2001) argues, "developing scientific understanding can be viewed as the appropriation of tools allowing students to build on their current knowledge while engaged in socially mediated activity (p. 28)." Further, if some revisions are expected to happen, there ought to be a balance among the three types of resources. For example, students depended on scaffolds from different resources in order to get access to modeling. Scaffolds built in the program are necessary, but scaffolds could come from other resources, such as the curriculum materials and the teachers.

Social Resources

The social aspect of modeling practices reflects student collaboration and communication with their peers, teachers, researchers, and other more knowledgeable individuals, such as water quality experts the teachers invited to their classes. This study demonstrated the socialization of middle school students when they co-constructed, evaluated, and revised their computer-based models over time. It expanded the current literature that pertains to college students and scientists (e.g., Bowen et al., 1999; Kozma et al., 2000).

Material Resources

The material aspect of modeling practices reflects the use of the computer-based modeling program (Model-It), student notebooks, booklets, and CompBooks, and other learning materials that the teachers provided. Around the shared space of the computer and the program, students were able to interact with rich material resources in order to construct their new knowledge of science as well as modeling. When the material resources became meaningful, which means students understood why, when, and how to use certain resources, the material resources became conceptual resources that they could make use of more flexibly and purposefully.

Conceptual Resource

Conceptual resources fostered student conceptual understanding of subject matter and the nature of models and modeling as scientific enterprise. In the study, guideline sheets (e.g. the background information search guidelines) provided a series of questions or guidelines that allowed students to find the right information without the teachers' involvement while still enriching student knowledge. The modeling critiquing guidelines provided criteria for students in presenting their models and giving feedback on others' presentations. Student investigation experience became a conceptual resource when they made sense of what they had investigated.

Critiquing and evaluating created an opportunity for students to understand how their models would be assessed. It provided an opportunity for students to understand the purposes of their modeling practices (Frederiksen & Collins, 1989). This was first scaffolded by the teachers; students were then able to create their own judgment system over time. In order to make full use of the conceptual resources, there is a need for providing timely feedback and opportunity for student to revise their models. Students also need to know how to revise and why they need to revise their models. Students also need to write down the feedback and comments and have time to do the revision. In general, the software tools, concepts, data, investigation experience, and life experience could all become conceptual resources when they are understood by students and become meaningful.

Implications

Based on the findings of this study, the following suggestions are provided for revising the curricula, software program, and teaching practices. They are made in terms of the three components of the learning environment in the theoretical framework (Figure 1.1) because they are all very important and need to work together. For instance, a software feature cannot successfully stand alone without a curriculum to make use of it and teachers to implement it in their teaching.

Using driving question to guide student modeling practices. As the results of WQII and the decomposition units show, a driving question as a shared focus (Krajcik et al., 1998; Novak & Gleason, 2001) initiated efficient and purposeful practices that students were not able to demonstrate during WQI. Therefore, as discussed in Theme 4, a driving question window in the software program that helps students to think through what they need to describe, and what and why they include certain objects, variables, and relationships seems to be necessary. Certainly, the emphasis can also be carried out through the curriculum and teaching practice.

Modeling knowledge needs to be emphasized. It is evident that student modeling knowledge as part of the nature of science is very important in taking advantage of modeling (Grosslight et al., 1991; White 1993). As the results have showed, students encountered difficulties when naming and deciding objects and variables, and filling in descriptions during their initial modeling cycles. Some students also questioned the purpose of doing modeling. Although teachers had previously introduced the relevant knowledge, it was insufficient or there was too much information for students to absorb in the one class period in which teachers introduced Model-It and modeling knowledge. Further, how to use the concept "variable" in Model-It could be introduced and used during student investigations. Iterative use of the concepts will also reduce the cognitive load for students.

Building software scaffolding to stimulate reflection. Visualization of the model layout and features in test mode helped students to reflect on their model and discover anomalies, which is considered critical for student learning (White & Fredricksen, 2000). However, when the model became more complex, it was more difficult for students to debug the models. A software feature that allows students to test individual relationship when they are creating them might help. This could help students create appropriate individual relationships in the first place. On the other hand, students were not able to troubleshoot the anomaly when two or more relationships affected the same variable from opposite directions. Therefore, even if each individual relationship works, the whole model might not function as students expected. As discussed in Theme 2, making the whole model's content visible in one place might help students to think through the whole model in terms of their intended goals.

Encourage making connections to student inquiry experience. Modeling is a process of explaining and interpreting natural phenomena with empirical data (Letour, 1987). Therefore, student inquiry experience is an important source of information and data that students need to use in order to describe a phenomenon accurately.

The curricula were designed in a way that allowed students to make use of their inquiry experience. Students were supposed to draw evidence from their investigation to support their decisions on including certain objects, variables, and relationships. However, the findings, especially during the Water Quality unit, show that students did not often make connections to their investigation experiences. There needs to be a specification of the level of detail in a model when asking students to make use of data from their investigation as well. If students start building a very specific model by using the conclusions from their investigation, students will be forced to use evidence from their investigations. Since the curricula use modeling in an iterative manner as the complexity of models increased, students can then build more general models when they develop a habit of making connection to their experiences and making arguments. If students are able to create models of the same phenomenon at different grain sizes, the modeling practices can extend to more general levels over time rather than simply repeat.

Foster a class culture of collaboration and critiquing. The results have shown that the classroom learning environment supported student collaboration. However, students could "work together" without much collaboration because some students did not communicate their ideas fully and did not treat their partners in a respectful way. A norm of collaboration needs to be emphasized. When students create good rapport across the whole class instead of only between a pair or a group, students might be more willing to provide comments and accept others' critiques. Further, improved modeling knowledge and understanding of what accounts for good models could also help students to be able to provide feedback and comments.

Future Directions

Since design-based research needs to address the learning environment and student learning comprehensively in order to accurately characterize the design, a vast amount of data were collected during the project. Because of time constraints, this study did not use all the data that were collected. For example, the replicated final models (Appendix H), replicated intermediate models in production (Appendix G), and transcribed pre-and post-interviews were not analyzed systematically. The following studies are expected to follow the study presented here. These studies also address some of the important questions that would expand the dissertation work.

First, there is a need to characterize student final models and their changes over time as part of the learning outcomes. I plan to analyze the products of student modeling practices—their final models and their changes over time.

Second, given the advantages of formative assessments (Toth et al. 2002), there is a need to look at the association between student modeling practices and their model in production. Such study can reveal how students interact with the intermediate models and how the models in production might influence student modeling practices. Since I have replicated student models in production using the process videos, it is possible for me to look at how student modeling practices associate with the intermediate models to answer this question.

Third, there is a need to systematically assess the change in student understanding of models and modeling. In order to answer the question, pre-interviews before student initial modeling in WQI, and post-interviews after iterative modeling cycles are needed. Since I have collected student pre-interviews and their post-interviews after the last modeling cycle of decomposition, I will be able to investigate student understanding of models and modeling (modeling knowledge) and its changes over time. Given student modeling actions and practices, it would also be worthwhile to look at how student modeling practices are associated with student understanding of models and modeling.

Fourth, although the process videos, classroom videos, and student models allowed me to look at student content knowledge, the recorded data showing student content understanding is too general and somewhat random because this question was not the major focus of the dissertation. Since content knowledge is heavily involved in student modeling practices, there seems to be a need to explore specifically the association between student content knowledge and modeling practices.

Finally, in order to warrant the usability, scalability, and sustainability issues (Fishman, Marx, Blumenfeld, Krajcik, & Soloway, in press), the design needs to be carried out with different populations. The results will develop and enrich the design, as well as the theory that generated the design, to better inform the design science community.

In a broad view, the following implications might be informative to colleagues in the field of learning technologies. First, in order to characterize student learning with technology, intensive observation as described in this dissertation is worthwhile to reveal student learning practices and issues that are related to those practices. Such description and exploration provides empirical evidence for creating functional learning environment. Second, since the modeling practices reveal student cognitive processes such as analyzing and synthesizing that might be universal for learning from scientific practices, they might apply to different learning situations. For example, researchers might be interested in exploring student modeling practices using different computer-based modeling programs or even without modeling programs to see whether students are able to perform similar modeling practices. Third, this dissertation concludes that student content knowledge, modeling knowledge, inquiry experiences, and metacognition are associated with student modeling practices. However, whether there are associations between those dimensions of learning is unclear and is important for further study.

In summary, the holistic account of student learning environment based on the design-based research approach will provide even richer information about how and what middle school science students might have learned through computer-based modeling. More cycles of design-based research might be necessary to help develop theory on the design as well as to scale up in order to disseminate the impact of the design.

Given the above discussion, certain limitations of the dissertation exist. First, although the data were collected over about 8 months of time, I did not follow the classes other than the modeling cycles although modeling was an integrated part of the curricula. Thus, I lacked a good understanding of the whole class history although I tried to understand it from talking to teachers and peer researchers who also conducted research in the same classrooms at the same time, and by looking at student notebooks, booklets, and curriculum materials provided by the teachers.

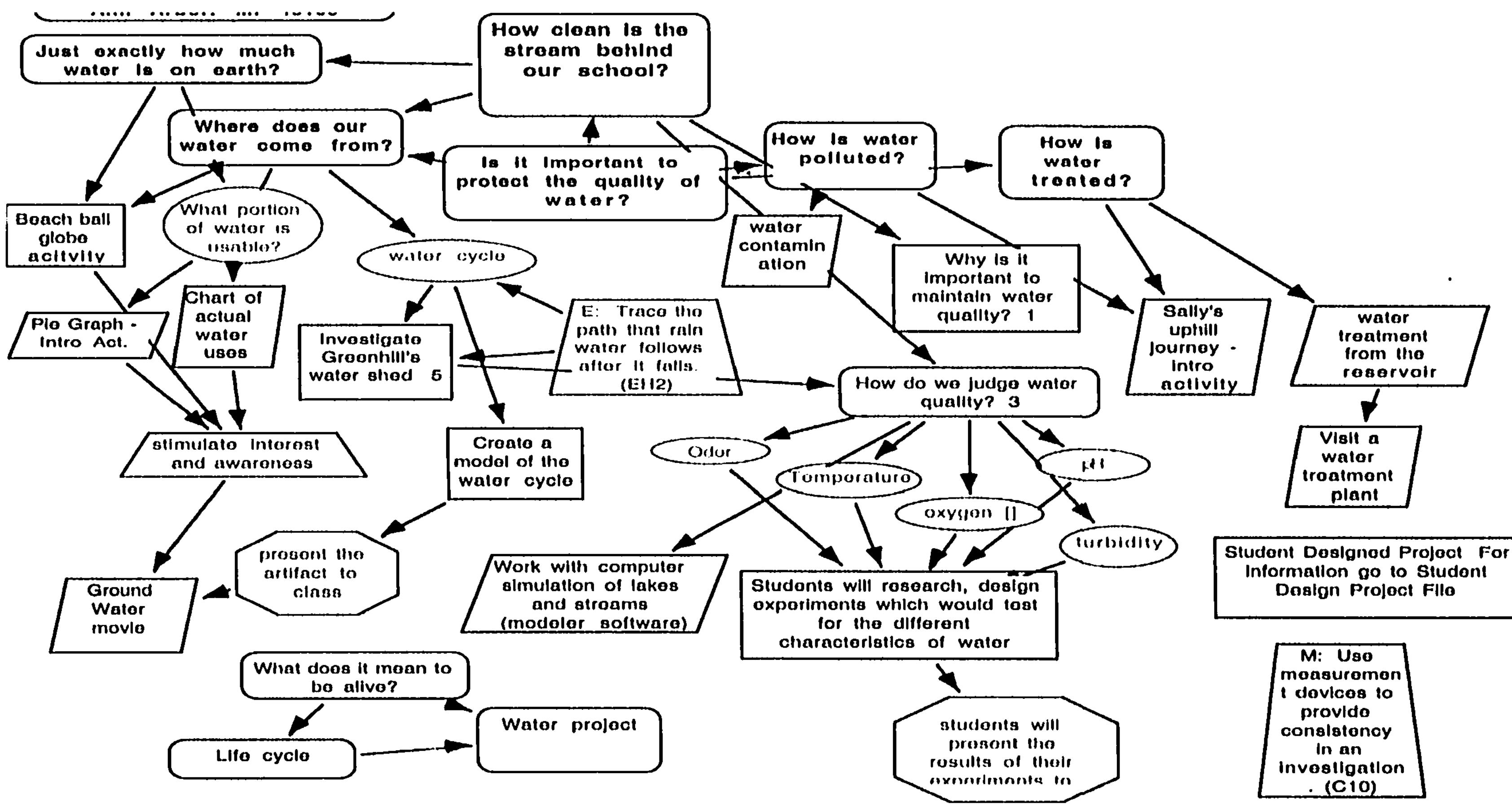
Second, I was not able to make use of data from a student modeling cycle in a weather unit when they went to eighth grade. Therefore, the longitudinal investigation of change in student modeling practices over time was undermined.

Third, the triangulation of student understandings was not complete without systematic analysis of student final models, intermediate models, content knowledge in their booklets and CompBook, and their understanding of models and modeling that were demonstrated in the pre- and post-interviews. These limitations will be considered when conducting similar research in order to enrich the knowledge of the field about how to design learning environments to help students to learn from computer-based modeling practices.

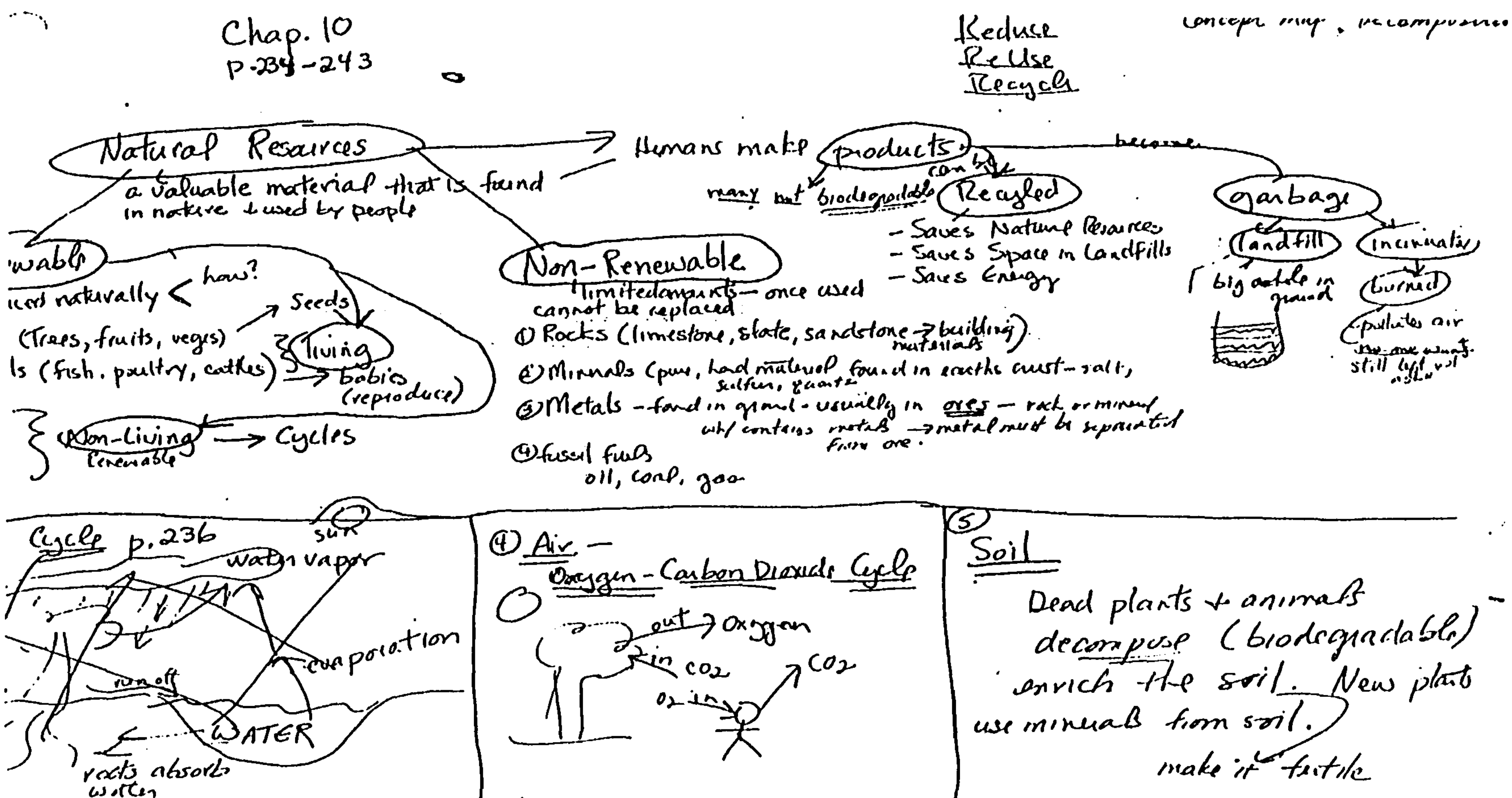
Despite these limitations, this dissertation expands the literature of modeling research including those studies on Model-It in the following aspects: First, it provides descriptions of middle school science student modeling practices and their changes over time. Second, it adds to the literature about how different aspects of student learning were involved in the modeling practices. Third, it provides theoretical and practical suggestions on how to better engineer the learning environment to facilitate student modeling practices through computer-based modeling. Lastly, it addresses the design principles of software scaffolding for science learning purposes from the perspective of computer-based modeling software design.

APPENDICES

APPENDIX A.
Major Concepts of the Water Quality Unit Provided by the Teacher



APPENDIX B.
Major Concepts of the Decomposition Unit Provided by the Teachers



APPENDIX C.

Exemplar Guidelines for Students Searching for Background Information

7th Science, Background information guidelines – DECOMPOSITION
Due: Thursday, Feb. 10, 2000.

Below are guideline and due dates for your decomposition background. Please follow this order. Use this sheet as a checklist. Label the paper, "Background information."

Decomposition

____ Define
____ What are decomposers? What do they do?
____ What are the four main types of decomposers?

DUE: THURS. FEB. 3

Solid Waste Disposal

____ Solid waste facts (introduce this section with a couple of solid waste facts)

Landfills
____ How are they constructed?
____ Advantages?
____ Disadvantages?

Incinerators
____ What are they?
____ Advantages?
____ Disadvantages?

Recycling

____ Define
____ Three reasons recycling is important (What do we save?)

DUE: MON. FEB. 7

Biodegradable vs Non-biodegradable

____ Define and discuss

Renewable and non-renewable resources

____ Renewable
____ Living Renewable – Define and discuss two examples
____ Non-living – Define and discuss two examples

____ Non-renewable
____ Define and discuss two examples

Bibliography

____ from library search and from class hand-outs

DUE: THURS. FEB. 10

APPENDIX D.
Detailed Description of Modeling Actions when Using Model-It

Mode	Modeling action	Detailed description of the action
Plan mode	Creating objects	Method 2 [Figure 1.1] Dragging an image (1) to the blank window area and popping up the object editor (2); (on the popped-up object editor) assigning object name (3); making it either as a background image or normal image (4); filling the description of the object in the description window (5); and clicking "OK" to dismiss the object editor (6). Method 1 [Figure 1.2] Clicking on the "new object" button (1) and popping up the object editor (2); (on the popped-up object editor) assigning object name (3); clicking the "select image" button (4) and opening the image folder (5); choosing a image (6); clicking on the "open" button to dismiss the image folder window (7); making it either as a background image or normal image (8); filling the description of the object in the description window (9); and clicking "OK" to dismiss the object editor (10).
	Deleting objects	[Figure 1.3] Clicking on an object icon (1) and opening the object editor (2); clicking on the "delete object button (3); clicking "OK" on the popped-up window (4) (Warning: the variables that were assigned to an object will be permanently deleted with the object!)
	Creating variables	Default textual initial value [Figure 1.4] 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).
		Customized textual initial value [Figure 1.5] 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); clicking on each of the three default values (i.e. high, medium and low) (6) and change it to desired textual value (7) and clicking "OK" to dismiss the "change value" window (8); deciding the initial value by changing the position of the slide (9); filling the description in the articulation box (10) and clicking "OK" to dismiss the variable editor (11).

		Numeric initial value [Figure 1.6] 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); selecting the variable range as "number" by clicking in the drop-down menu (5); changing or use the default numeric range (i.e. 0-100) (6); deciding the initial value by changing the position of the slide (7); filling the description in the articulation box (8) and clicking "OK" to dismiss the variable editor (9).
Build mode	Modifying variables	[Figure 1.7] Clicking the variable icon (1) to pop up the variable editor (2); changing the affiliation of the variable to a different object (3); changing the variable name (4); changing the variable range as "numeric" or "text" by clicking on the drop-down menu (5); changing the initial value by changing the position of the slide (6); changing the description in the articulation box (7) and clicking "OK" to dismiss the variable editor (8).
	Deleting variables	[Figure 1.8] Clicking the variable icon (1) to pop up the variable editor (2); clicking on the "delete variable" button (3) and it's done. (Warning: there is no confirmation window for variable deletion yet, so be careful when you make the decision.)
	Creating relation-ships	[Figure 1.9] 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).
	Modifying relation-ships	[Figure 1.10] Clicking on the small square icon between two variable that denotes the relationship between them (1) and popping up the "relationship editor" (2); changing the relationship to "decreases" or "increases" by clicking on the drop-down menu (3); changing the degree of change by clicking on the drop-down menu (4); changing the "because" statement (5); and clicking "OK" to dismiss the relationship editor. (Warning: if you change the parameters the "because" statement will be erased so that you have to retype in the "because statement".
	Deleting relation-ships	[Figure 1.11] Clicking on the "relationship" button; clicking on the "delete" button (2) and clicking "OK" on the popped-up confirmation window (3). (Warning: there is no confirmation window for relationship deletion for version 3.0 and earlier version yet.)
Plan, Build, &Test mode	Moving	[Figure 1.12] At each mode, there is a "move" button. Clicking the "move" button (1) so that a user can move the icons on the computer screen (2), such as the position shown on the graph (3).

Plan & Build mode	Saving	[Figure 1.13] Going to Plan or Build mode; Clicking on "File" on the upper left corner of the program (1); (On the drop-down menu) clicking on "Save" or "Save as" to save a model (2). (Note: there is a requirement for the name of a model: Only upper or lower cases and numbers were allowed but there should be no space, or other non-text or non-numeric characters.)
Test mode	Creating meters	[Figure 1.14] Clicking on the "meter" button (1) and clicking on the variable icon to pop up the meter (2) that is associated to the variable. A variable can be either an dependent variable (3) or Independent variable (4) (Note: a graph line that is of the same color as the meter and also demonstrates the initial value of the variable will appear on the simulation graph area at the bottom of the program layout.
	Moving meters	[Figure 1.14] Clicking on the "move" button (5) and move the meters around.
	Adjusting meters	[Figure 1.14] Clicking on the "Rew" button and the position of a slide will change to the position of the initial value of the variable; (6); a graph line that is of the same color as the meter also demonstrates the initial value of the variable (7);Clicking on the slide bar on the meter of an independent variable will start a simulation. Clicking on "stop" button will stop the simulation (8). An example of the independent variable change with the changes in other variables is shown at point #10.
	Minimiz-ing meters	[Figure 1.14] Clicking on the small arrow the upper right corner on a meter can dismiss the meter (11). (Note: the meters do not disappear until you go to another mode. Therefore, if you scroll down you can still find the minimized icon. You can click on it and the meter shows up at the same place as it was dismissed.)

Note: 1. The modeling actions can be executed in Model-It version 2.99Z2 or earlier version that were created on Java platform; Please refer to figure 3.1, 3.2, 3.3, and 3.4 and Model-It section in Chapter 3 to know the program better.
2. The order of the operation might change according to student preference.

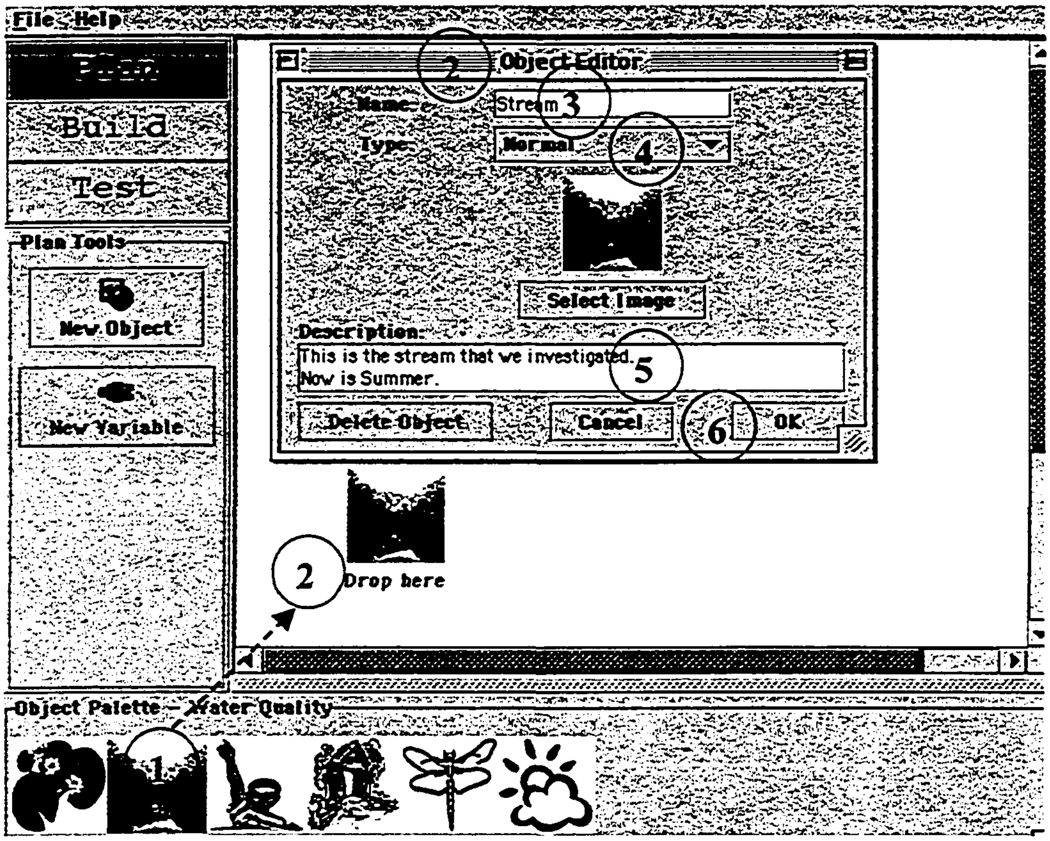


Figure 1.1. Plan mode-Creating objects (Image from palette)

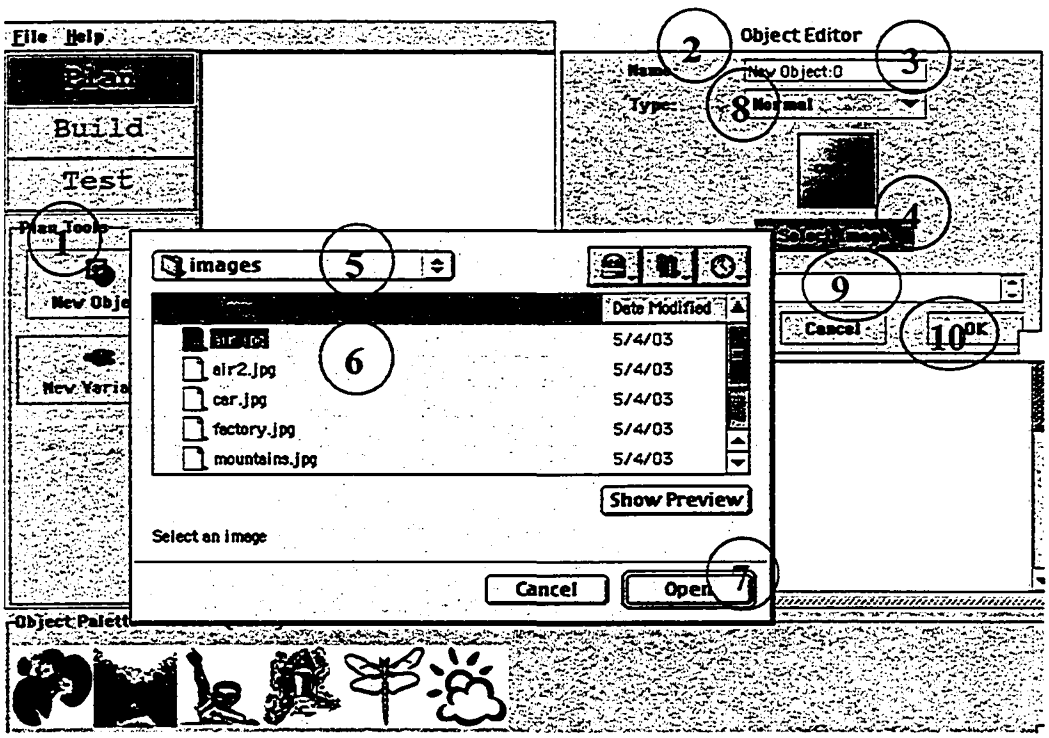


Figure 1.2. Plan mode-Creating objects (Image from "select image" folder)

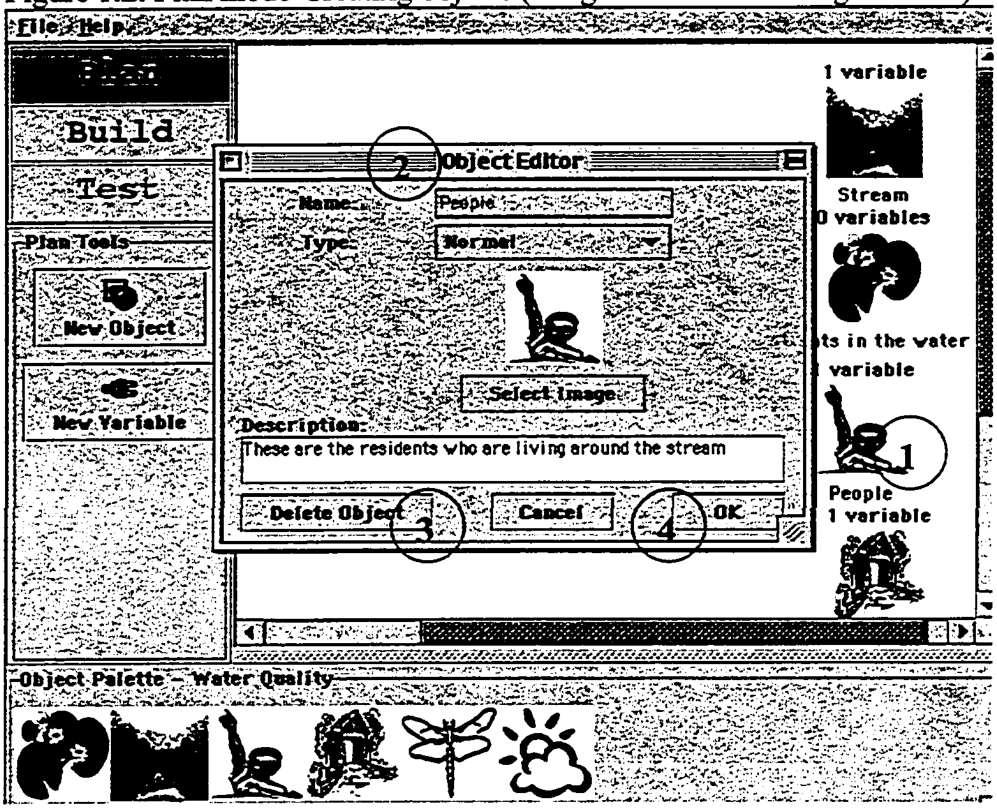


Figure 1.3. Plan mode-Deleting an object

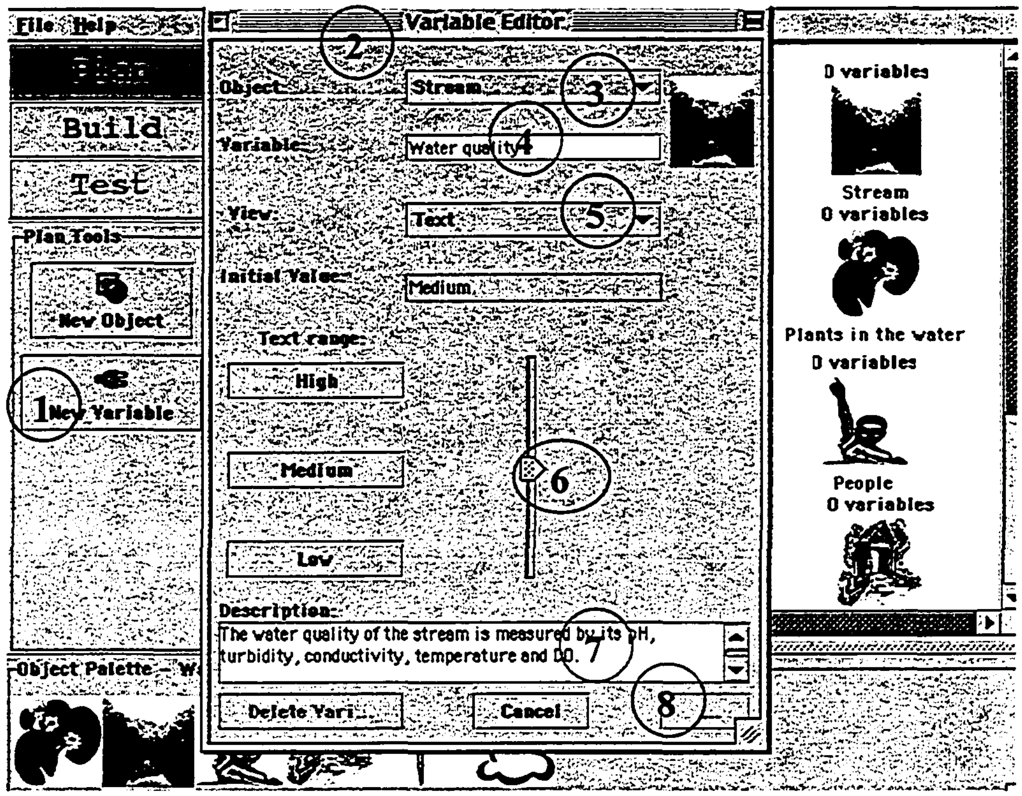


Figure 1.4. Plan mode-Creating variables (Initial value as text)

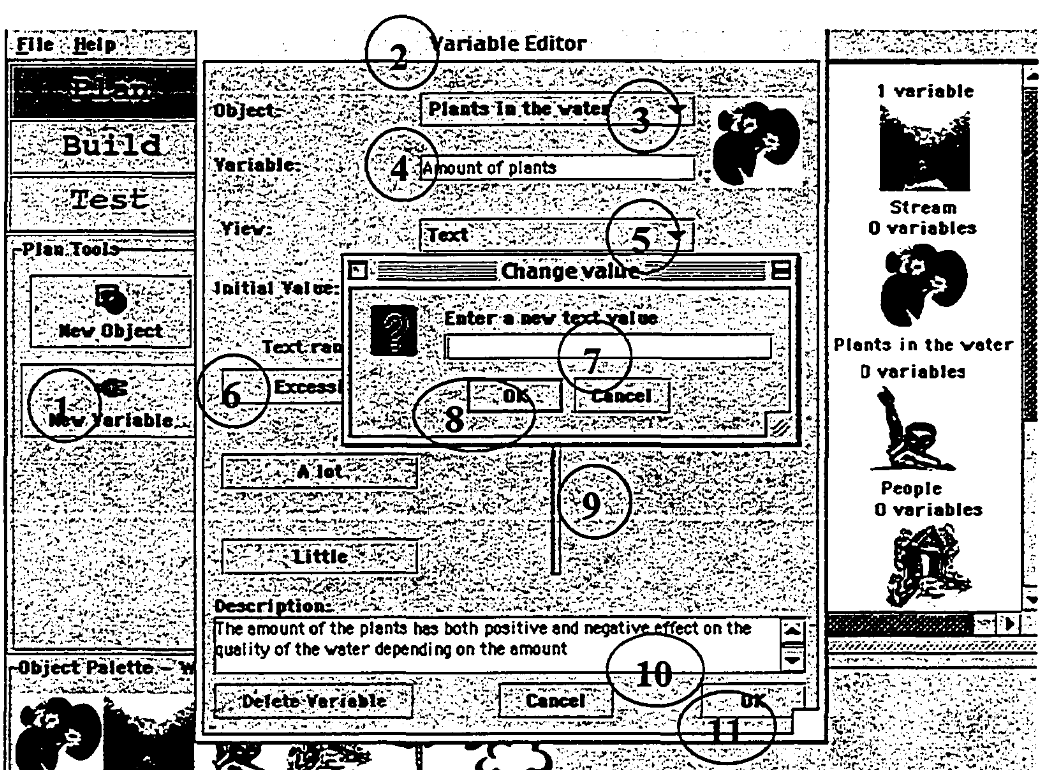


Figure 1.5. Plan mode-Creating variables (Customized an initial value option)

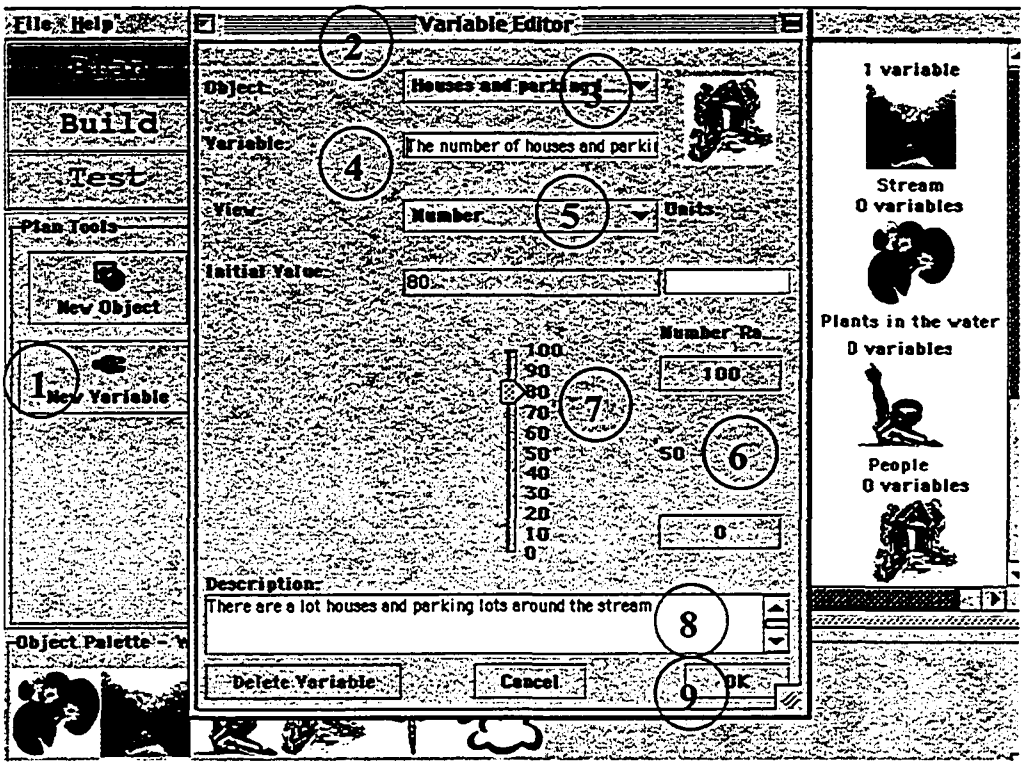


Figure 1.6. Plan mode-Creating variables (Initial value as number; the range is customizable)

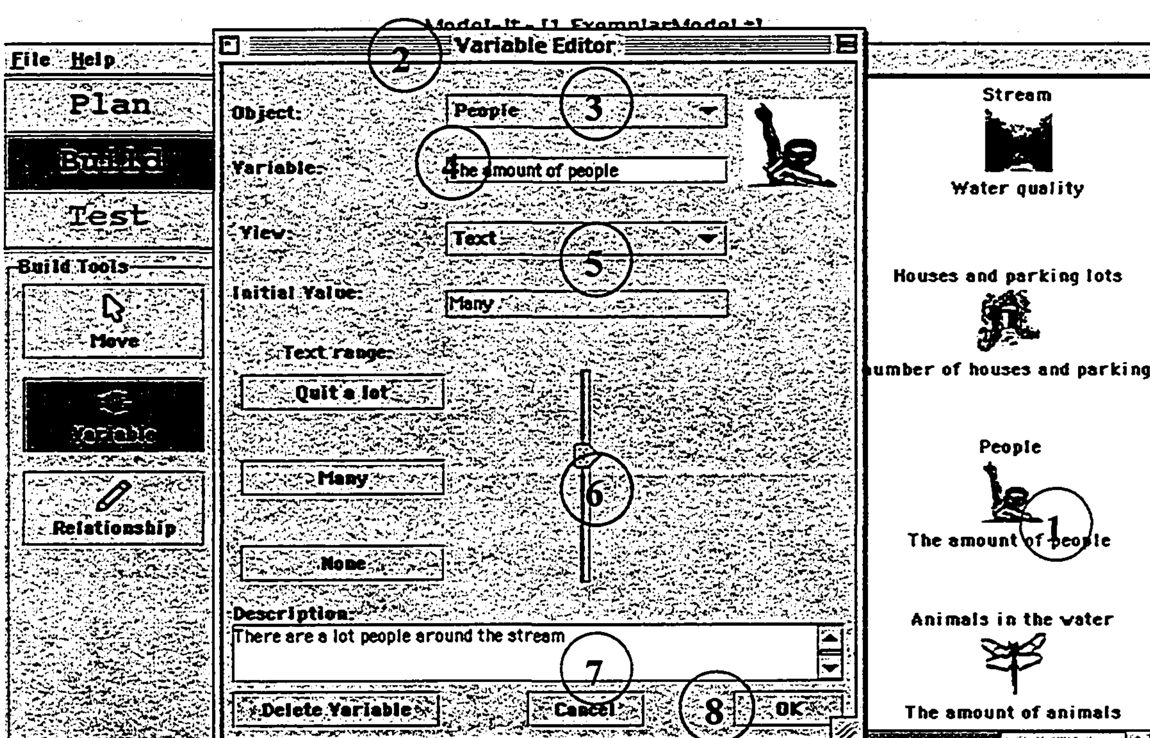


Figure 1.7. Plan mode-Creating variables (Initial value as text)

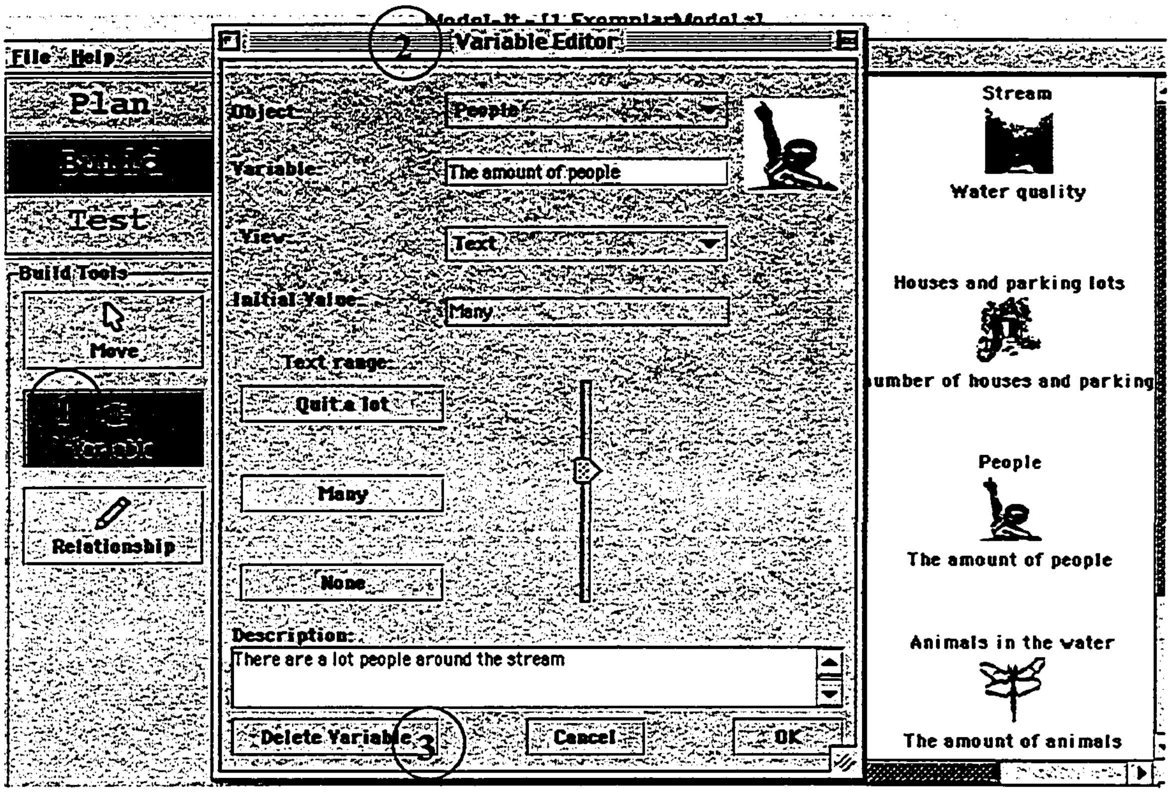


Figure 1.8. Plan mode—Deleting a variable

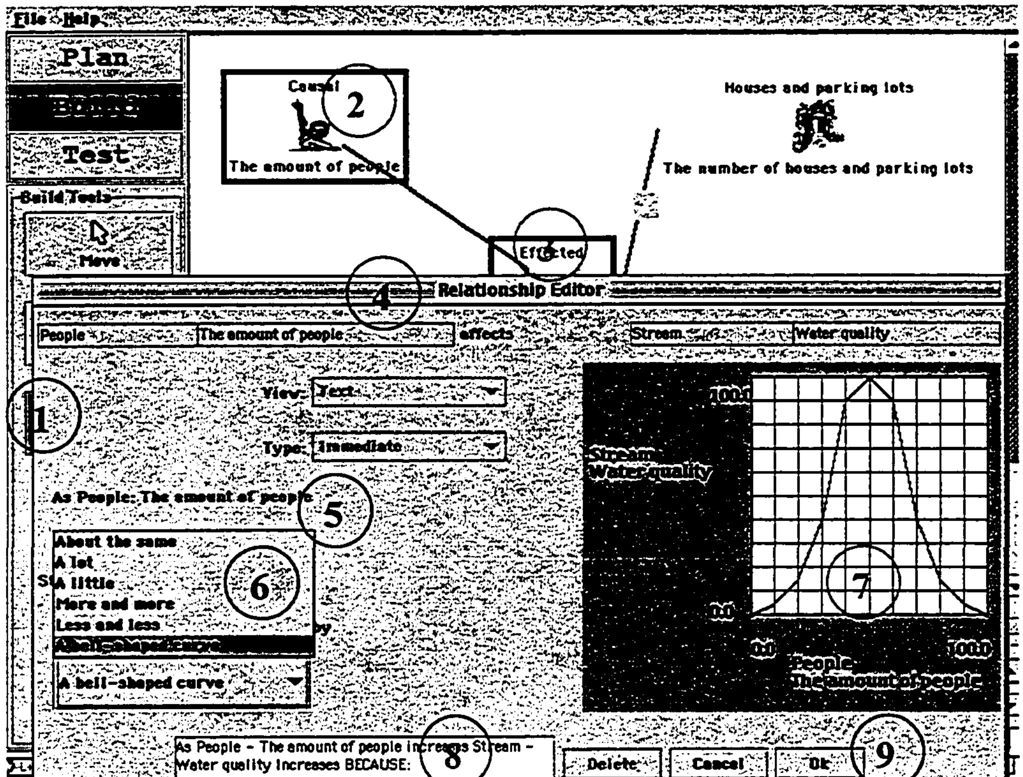


Figure 1.9. Build mode-Relationship editor (Options of degrees of changes)

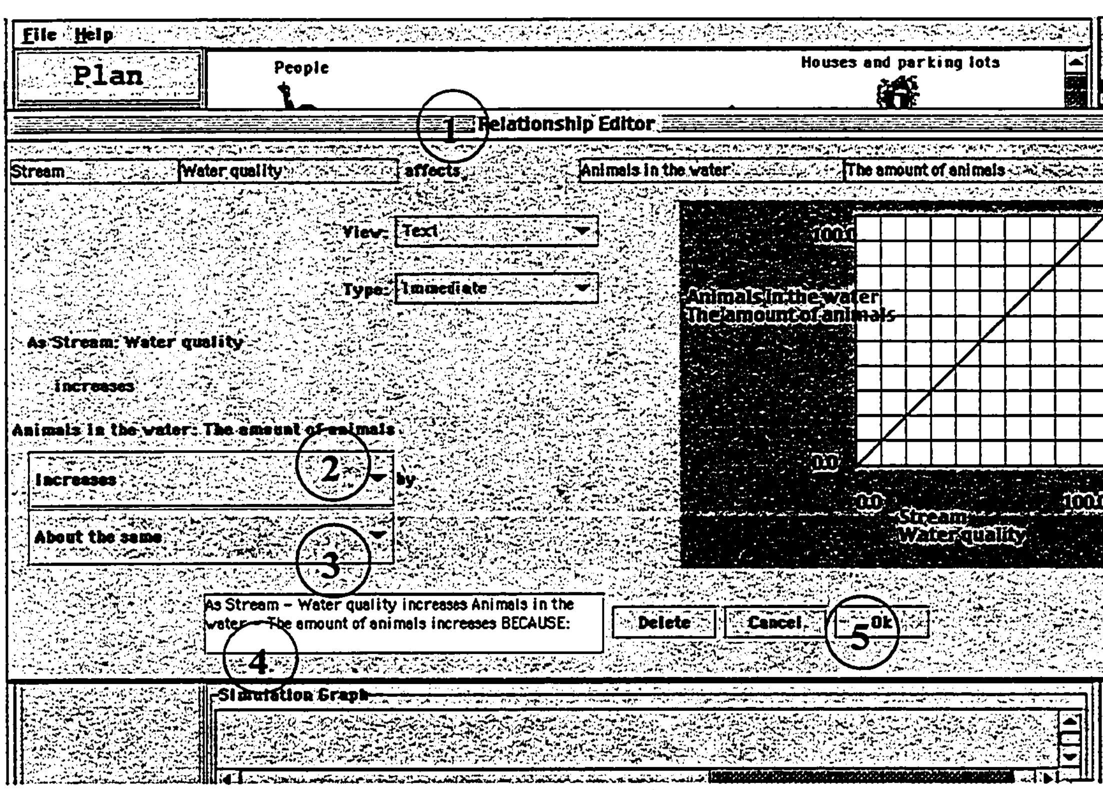


Figure 1.10. Build mode—Modifying a relationship

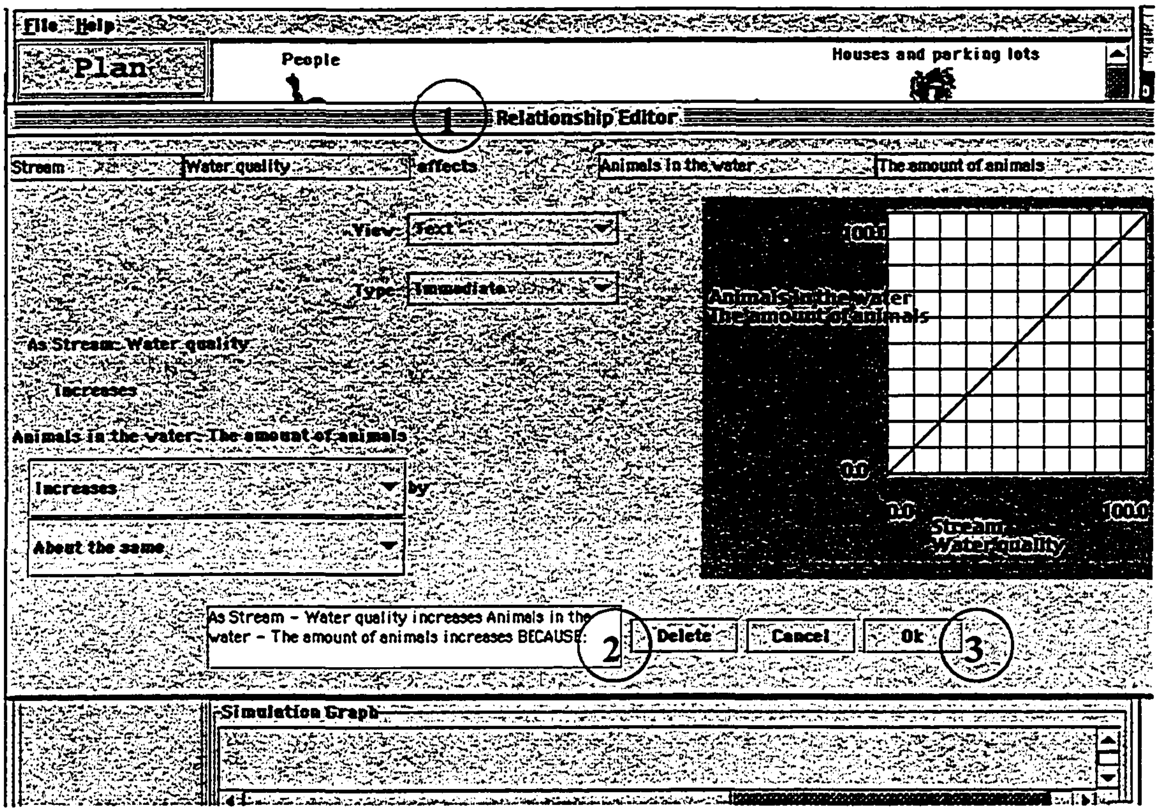


Figure 1.11. Build mode—Deleting a relationship

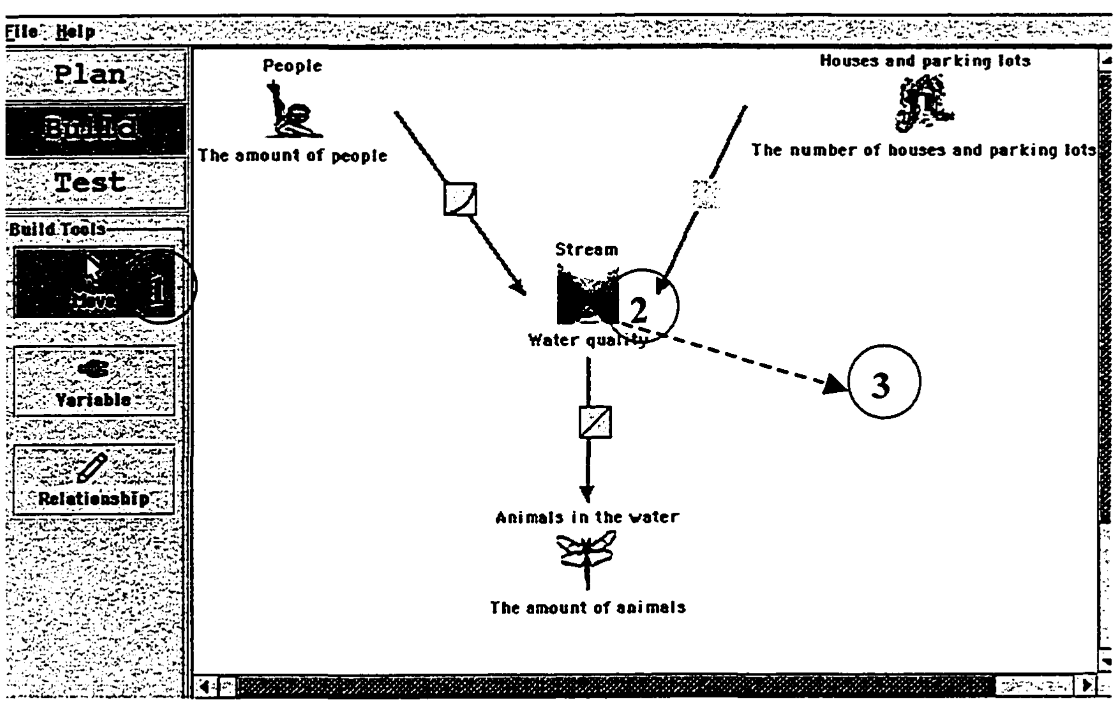


Figure 1.12. Build mode—Moving button

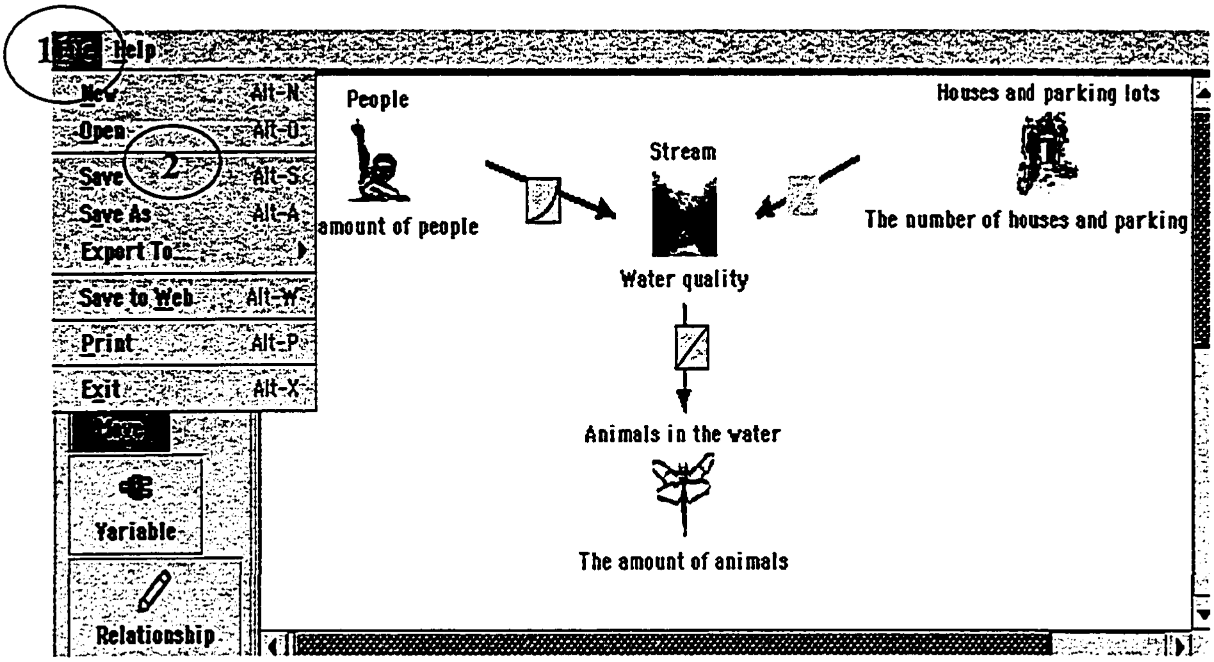


Figure 1.13. Saving a model

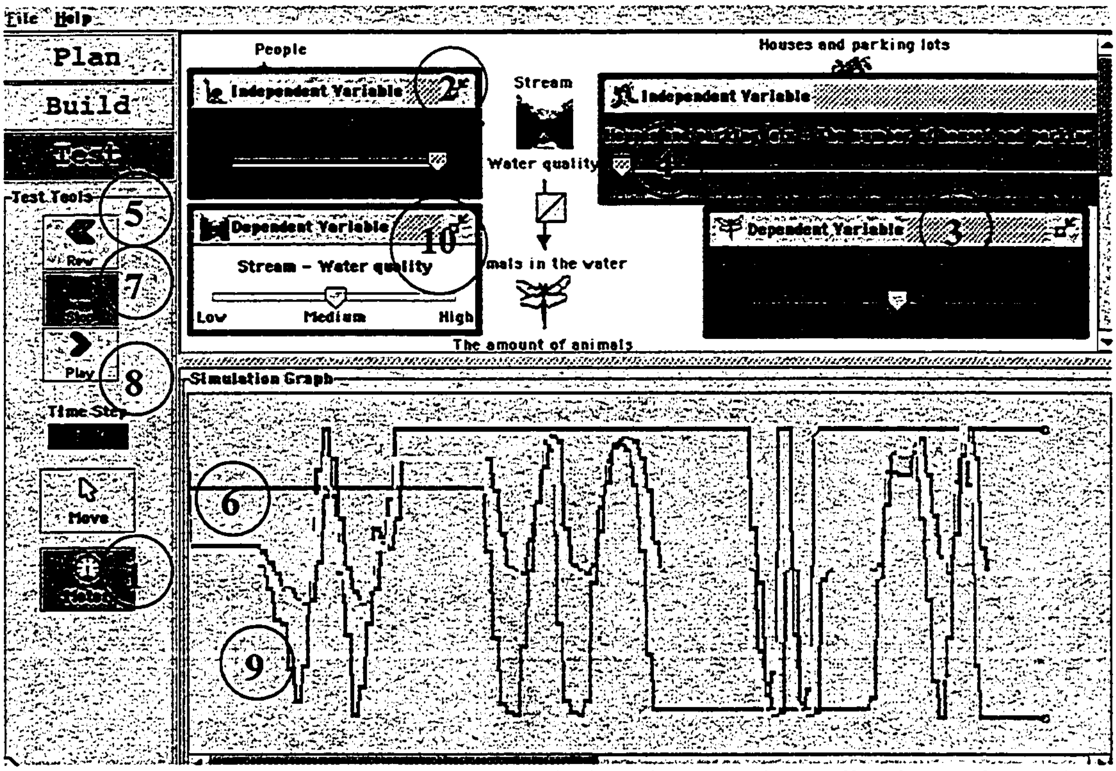


Figure 1.14. Test model—Testing a model (Creating, moving, adjusting and deleting meters)

APPENDIX E.

Definitions of Modeling Practices (Including Sub-categories), and Examples

Modeling practices	A modeling practice reflects the essence of student modeling actions and conversation as cognitive behaviors that emulates or mirrors the practice of scientists.	**Examples** (Examples are from the data set of either direct quotation or summaries.)
3.1 Planning	Planning includes practices of decision-making regarding the driving question or scenario to be modeled, objects, variables, and relationships in a model (usually) before actually building a model (at brainstorming stage).	
3.1.1 Stating goals	Students decide what their driving question and sub-questions are, what scenario they have for their model, or articulate what kind of model they want to have.	1. Our driving question is "how clean is the stream in my community?" 2. I am going to model the decomposition of daily garbage of my house. 3. I want a simple model 4. I want to the model to be as complex as possible so that we can include all the variables that we have.
3.1.2 Identifying objects	Students talk about what objects to choose; discuss which are relevant (or not relevant) to their driving questions or modeling goals.	1. There are not much factories in Ann Arbor, should we include factory in our model? 2. This picture looks like a mountain, let's use "mountain side road" as the object name.
3.1.3 Identifying variables	Students talk about what variables to choose; discuss which are relevant (or not relevant) to their driving questions and/or modeling goals or the objects and/or what initial value they should assign to a variable.	1. I think we should consider the distance of trees to the river bank. It would affect the amount of leaves that fall into the stream. 2. Seasons can be a variable that affect temperature. Let's make the initial value option as winter, spring/fall and summer.
3.1.4 Discussing relationships	Students talk about between what variables they need to create relationships and what the relationship should look like.	1. I think we need build relationship between the amount of cars and water quality because cars bring salt from the bridge into Huron River. It should be "more and more" because the more cars run across the bridge the more salt is brought into the water.

3.2 Analyzing	Analyzing involves student statements and actions that decompose a large system or a phenomenon that they are going to model into sub-systems or components. The purpose is selecting the appropriate objects, variables and relationships to reflect the most important characteristics of the phenomenon in terms of the focus of the model. It may also involve student meta-cognition or reflective behavior so that they can decide what they should do next.	
3.2.1 Specifying objects	Students create objects with actions and conversation of deciding object names, descriptions and providing reasons for their decisions.	1. Ok, object name, parking lot…any idea for the description? 2. Do we need to have the two towers of decomposition as objects?
3.2.2 Deciding variables	Students create variables with actions and conversation of assigning names, providing descriptions, and choosing initial values.	1.Q: …so what initial value we should have for turbidity? A: it seems to depend on seasons. 2. What was the turbidity in our stream?
3.2.3 Defining relationships	Students create relationships with conversation and actions of connecting variables, defining the relationships and providing reasons for their decisions.	1. I think salt affects turbidity a lot in the winter in Ann Arbor, should we use "a lot" or "more and more"? 2. Should we differentiate "the amount of decomposition" and "rate of decomposition"?
3.3 Synthesizing	Synthesizing practices are indicated from 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 or use their investigation experience for explanations and making arguments.	
3.3.1 Elaborating relationships	Students discuss correlation or cause and effect relationships in terms of the whole model with reasons or explanations. (The difference between this one and 3.2.3 is that 3.3.1 involves discussion that is more than one relationship and usually is in terms of the whole model.)	1. Alisa and Charles?
3.3.2 Predicting	Students express their ideas about what should happen with their consecutive modeling actions. (Note: I assume that reasonable predicting, which is new ideas, is based on considering the consistency of ideas in a model, which is synthesizing.)	1. What if I change the relationship between the variable FACTORY-emission and STREAM-water quality from linear to non-linear? 2. It should do…when we run it.
3.3.3 Connecting to	Students refer to their investigation experience or teachers' instruction as evidence in supporting their decision when	1. We had low conductivity (in our investigation), right?

experience	instruction as evidence in supporting their decision when deciding their objects, variables or relationships.	
3.4 Evaluating	Evaluating practices include statements and actions that students talk about the quality of their model; present their model to others to get feedback or test the model in order to improve their model.	
3.4.1 Critiquing/interpreting test results	Students make comments or interpretation when they are testing their models according to certain criteria.	1. It's working! 2. When "people increases" the number of trees decreases… and water quality decreases, that's correct.
3.4.2 Identifying anomalies	Students encounter unexpected findings.	1. A student found that they could not change the slide bar in the meter of a dependent variable. 2. Why with acid rain increases water quality did not change much? 3. Well, nothing happens when I change the variable?
3.4.3 Identifying/proposing solutions	Students suggest what to do to fix something unexpected or anomalies they discovered.	1. I think that stream quality does not decrease too much is because degree of the relationship between turbidity and stream quality was set as "about the same."
3.4.4 Carrying out solutions	Students actually do their proposed solution.	1. Students create a stream quality variable after discovered that they did not have that variable yet when creating relationships.
3.5 Reflecting and monitoring	Reflecting and monitoring practices are modeling actions and statements that demonstrate student self-awareness of the control of modeling processes, their need for help and resources and so on. The practices show student metacognition.	
3.5.1 Seeking information	Students ask either their teacher or their peers for answers of content knowledge, or modeling ideas.	1. Do you know how to delete a variable?" 2. "How can I change the initial value?
3.5.2 Gathering resources	Students check their note, search online resources or go to library to gain more information about their project and model. (The difference between this one and 3.3.3 is that this code	1. (Sound from the video indicating a student is opening a book or notebook) Let's look at what we have in our textbook?

	captures activities that do not have an solution handy, they have to take some effort in order to get the results they want.)	
3.5.3 Deciding about course of action	Students state what they are going to do next. (Note: to put this practice here is because a student might have to go through Analyzing so that he/she can make a decision from different options.)	1. Let's go to build mode because we have already had enough variables. 2. The model is too complex, let's test it now
3.6 Publicizing and communicating	There are many ways of communicating, but this category captures the conversation and actions that involve students, teachers or researchers other than the two or three students in a pair or a small group. This does not necessarily limited to there class presentation because students talk to their teachers, researchers or other peers during their modeling processes. Students present their models to the class or put them on their web sites for getting comments and feedback from their teachers, peers or more knowledgeable others.	
3.6.1 Self-critiquing and reflecting	A student realizes issues or anomalies when presenting a model to the class.	1. Well, the number of trees affects water quality by causing erosions, so I think we need a variable "turbidity" in between of the two variables.
3.6.2 Peer evaluating	Classmates besides the student pair critique and comment on the model that student pair presented.	1. I think they should have pavement and sidewalks there because when they were heated and it rains, water from pavement and sidewalk could cause thermal pollution.
3.6.3 Teacher evaluating	A teacher in the class critique and comment on the model that student pair presented.	1. It's good that some of you have used the bell-curved line correctly.
3.7 Others	This code leaves spaces for emerging themes in terms of students modeling practices.	

APPENDIX F.
Process Video Transcription Guidelines

Major principles:
1. The transcription should capture most of the conversation (Oral discourse) and some typical cases need to be transcribed verbatim;
2. Descriptions of screen activities so that the transcripts are understandable to readers without looking at the Process videotapes.
3. Descriptions should be as specific as possible with who, what, when, where, how an event happened.

Details:
I. Segmentations of text (see Chapter 3, pp. 50-56 for the definitions of the different units of analysis).
1. Time mark at any starting point of a new mode (i.e. Plan, Build, or Test) or Something of different interaction pattern (e.g. Technical problem and trouble shooting; off-task).
2. Within each mode, put a time mark with creating or modifying any new object or variable if there is any conversation involved.
3. For student conversation, each time there is a turn to the other person, start a new line. Even for the same person, each idea starts as a new line.
4. Chunks divided by mode and segmentation (at episode level) with a time mark.

II. The following modeling actions were described in ( ) on the transcripts. However, for convenience, most of the following actions actually were not in ( ).
1. Launching the program
2. Plan mode
2a. Drag a ready-made image from picture palette vs. search for image button.
2b. Object editor:
Name an object,
Write description of the object
2c. Variable editor:
Name of the variable,
Write description of the variable,
Assign initial value of the variable: Default (High/medium/ or low); Customized (e.g. Excellent, good, or poor)

3. Build mode
3a. Variable editor:
Name a variable,
Write description of the variable,
Assign initial value of the variable:
3b. Relationship editor
Connect A to B (From A to B means A is an independent variable)
Write description of the relationship (see the following sample)

4. Test mode
4a. Open meters (Name what was opened)
4b. Point the cursor to graphs
4c. Move meters
4d. Rearrange meters
4e. Delete meters

III. Researcher notes [ ]
These notes can help the researcher code, analyze the data, and write summaries afterwards.

Three distinct things:
1. Description: Totally faithful to what happens.
2. Explanation in ( ), researcher helps readers about the situation according to what happens before or after an event. Totally faithful with what happened.
3. Interpretation in [ ] Researcher's educated guess with other relevant information in mind.

Sample Transcript that Shows how I Applied the above Guidelines

(Note: the following transcript was adopted from our pilot study.
I used this as the example because I wanted to show that for our initial transcription of the PVs, the following example was used to acquire consistency among us, the three student researchers)

* School: XXXX
* Teacher: Jack
* Unit/Exposure: Water Quality 1
* Day: 1
* Grade: 7
* Student 1: Rich
* Student 2: Ally
* Student 3:
* Date: 3/17/2000
* Period: D
* Tape No.: 010
* Video: Process
* Transcriber:
* Coder:

0026 {Time mark is four digits, MMSS}
As Ss are launching Model-It... {Summary or description of modeling actions and some times participants' conversation}
Rich: Do you wanna use what we put down? {Use first/last initial when student can be identified; a sentence in this manner is a direct quote of the speaker are own words.}
Ally: If we didn't use turbidity...
S1: So, does conductivity raise or lower pH? {use S1/S2 when student cannot be identified}
S2: (long pause) Lower. {Modeling actions are in parentheses if necessary.}

0054
S2: Choose water (refers to choosing unit in menu of choices; S1...) {Screen activities were also parentheses}

0109
-----PLAN {Specification of mode}
Rich: Let's create the stream
Students try to create object using the New Object button, but get confused looking for custom icon file.
They cancel and try dragging picture from the lower palette. {Description of screen activities}
New object - CREEK, normal, custom icon, no description. {standard OBJECT text, if there is description, try to capture it. In order to be save spece and time, any modeling actions of "creating" such as this one "creating" New object is by default transcribed in the way it is.}

Rich: Should we add some variables for this stream?

0209
New Variable - CREEK turbidity, text (excellent/fairgood/poor),
Initial value: excellent, no description. {standard VARIABLE text, noting (new text) and initial values only when students changed their default setting like this, which means they changed the scales from "high", "medium" and "low" to new text scales.}

While creating this variable,
Ss try to make it numerical, and get confused by the display when they change the range, then they say they understand, change back to text
{Was a summary. Detailed transcription is needed. }

0409
New Object - ANIMALS, normal, custom icon, no description.

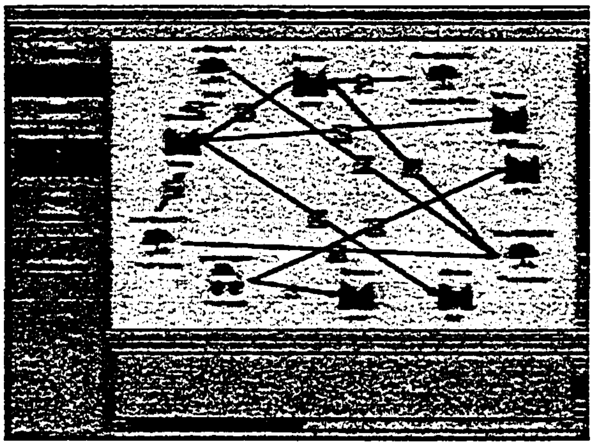
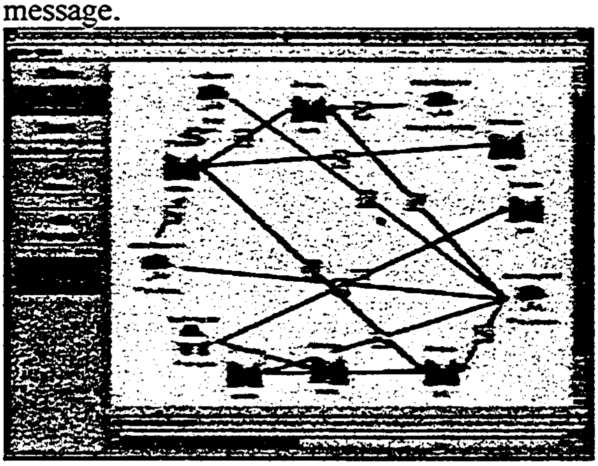
0500
-------BUILD
T: why would it be number, how could you do that?
Think about that? {Teacher as "T" and Student teacher as "ST"}

0530
{Create relationship} As mold increases, how much decomposition increases by a little BECAUSE... {Standard RELATIONSHIP text}

0615
------- TEST
Ss open 5 meters: the amount of salt...{I had to use "..." when something was not clear or not critical so that could be omitted.}
Re-arrange the variables on screen;
then change the value of the amount of salt on the meter.
The change value of variable: conductivity.
Ss observe the change.}
{Use Ss to indicated students, not "they"}
Rich: Why does turbidity go down?
{Ss manipulate the same two variables rapidly,
making noises,
commenting on the "pretty graph"
(the lines in the graph area criss-cross as they manipulate variables)}
(laughing)

{Research notes as background or complementary information to better interpret the results.}

APPENDIX G.
WQI: Intermediate Models Replicated from PV: Nathan and Kelly, December 11, 2000, Day3

2346, After Nathan rearranges the icons, the tree leaves at the lower right corner seems to be the core variable.  3347, Too bad Ss were not able to save this model because they keep getting a warning message. 	Driving question or scenario (according to the process videos or student pair's class presentation): Day2, 0000, When asked, Ss say that their question was about trees and DO. Objects: 1. Day2, 0250, No name, normal, (tree icon), Desc: (no.) {0520, R asks, Ss say they were not able to change the name.} 2. Day2, 1216, STREAM, normal, Desc: (no). 3. Day2, 1607, PARKING LOT, normal, Desc: a big black thing. Variables: 1. Day2, 0556, TREE: the number of leaves, text, Initial value: high, Desc: the number of trees will affect the number of leaves aall into the water. The number of trees will affect turbidity. 2. Day2, 0733, TREE: the number of trees, text, Initial value: medium, Desc: the number of trees will affect the number of leaves and will affect turbidity. The more trees the more shades. 3. Day2, 0824, TREE: the size of trees, text, Initial value: between medium and low, Desc: the size of the tree will affect how much sun is blocked.

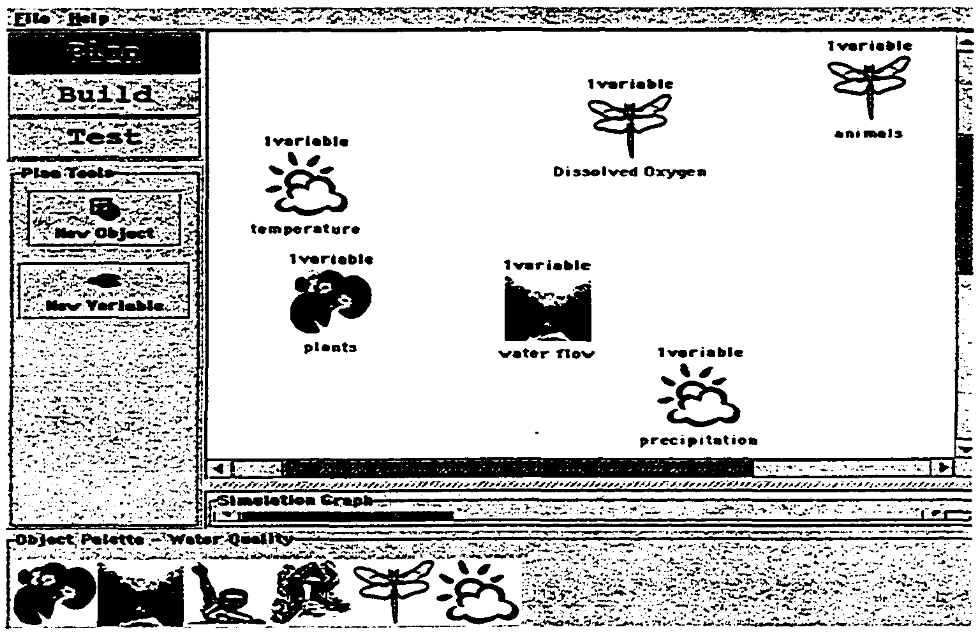
4. Day2, 0951, TREE: the location of trees, text, Initial value: default Desc: The location of the tree(s) will affect the amount of leaves fall in the river. 5. Day2, 1507, STREAM, text, Initial value: medium/high, Desc: STREAM size affect temperature to a certain points because the deeper the stream, the lower the temperature. 6. Day2, 1741, PARKING LOT: the number of cars, text, Desc: oil and antifreeze leaking and salt..pollution. 7. Day2, 1826, STREAM: temp. text, Initial value: default, Desc: The temp...[Lower temp. means high DO] 8. Day2, 2054, STREAM: turbidity, text, Initial value: medium, Desc: the...affect temp. 9. Day2, 2141, STREAM: pH, text, Initial value: default, Desc: (No). 10. Day2, 2200, STREAM: conductivity, text, Initial value: high, Desc: (No). 11. 0609, STREAM: DO, text, Initial value: High, desc: the amount of dissolved oxygen. 12. 2710, STREAM: speed, text, Initial value: default, Desc: how fast it goes?
Relationships: 1. Day2, 2354, (As) PARKING LOT: the number of cars (Increases) STREAM: turbidity (Increases) by (A little) (BECAUSE) salts on the road/parking lot = higher cond. 2. Day2, 2440, (As) PARKING LOT: the number of cars (Increases) STREAM: pH (Increases) by (A little) (BECAUSE) anti-freeze is not so much... 3. Day2, 2535, (As) TREE: the number of leaves (Increases) STREAM: conductivity (Increases) by (A lot) (BECAUSE) more leaves will stir... 4. Day2, 2646, (As) TREE: size (Increases) TREE: the number of leaves (Increases) by (more and more) (BECAUSE) more leaves will stir... 5. Day2, 2833, (As) TREE: size (Increases) SREAM: temp. (Decreases) by (A little) (BECAUSE) (cannot see). 6. Day2, 2925, (As) TREE: # of trees (Increases) TREE: the number of leaves (Increases) by (A lot) (BECAUSE) (cannot see). 7. Day2, 3050, (As) TREE: location of trees (Increases) TREE: the number of leaves (Increases) by (A little) (BECAUSE) the closer the trees to the stream the more chances that leaves will fall into the river which will raise the turbidity. 8. Day2, 3219, (As) TREE: # of trees (Increases) STREAM : temp. (Decreases) by (A little) (BECAUSE) the more trees the lower the temp. 9. Day2, 3430, (As) TREE: TREE- size of trees (Increases) STREAM : temp. (Decreases) by (A little) (BECAUSE) the bigger the trees the lower the temp. 10. 0842, (As) STREAM : temp. (Increases) STREAM : DO (Decreases) by (A lot) (BECAUSE) higher temp., poorer D.O., poorer WQ 11. 2130 (As) STREAM : turbidity (Increases) STREAM : temp. (Decreases) by (A little) (BECAUSE) (cannot see). 12, 2548, (As) (As) TREE: the number of leaves (Increases) STREAM : DO (Decreases) by (A little) (BECAUSE) when leaves decompose... 13. 2838, (As) (As) STREAM: speed (Increases) STREAM : DO (Increases) by (A little) (BECAUSE) the faster the stream, the more DO will be trapped in.

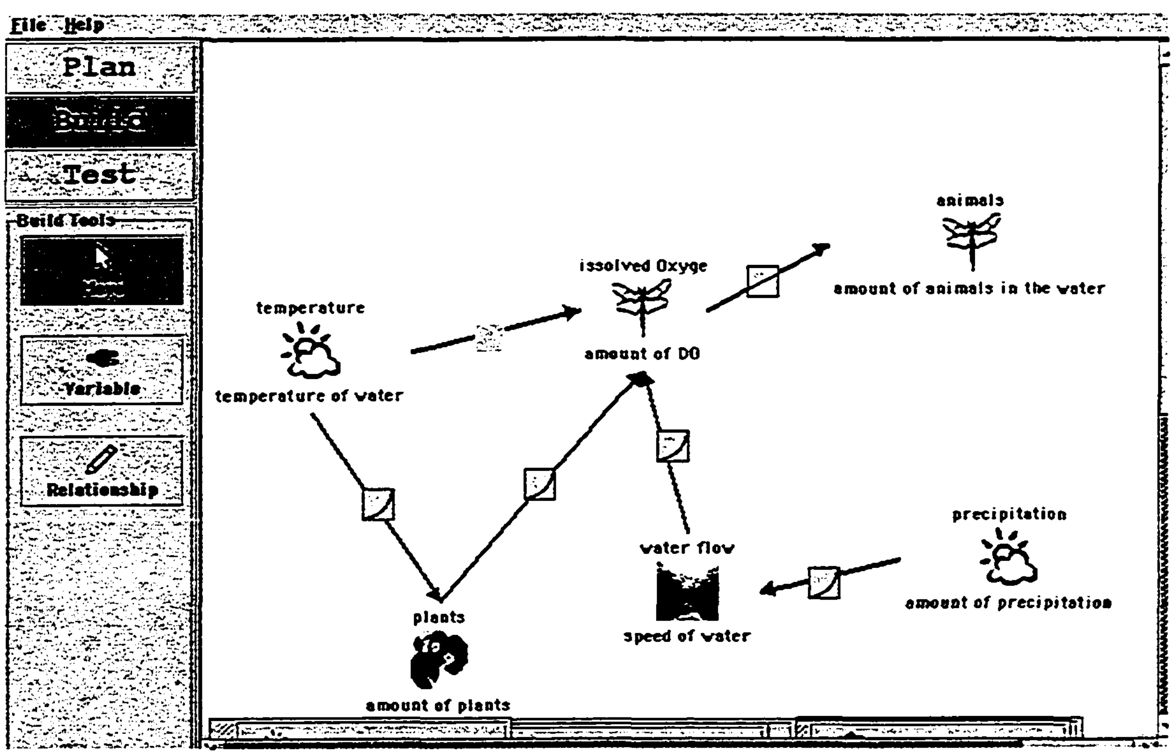
APPENDIX H.

WQI: Final Models Replicated: (C period) Don and Abby, January 10, 2001

(**Note:** this final model was replicated from a model dated as Jan. 10, 01)

(File name: alexdean, opened with Version 2.99Z2)





WQI: Final Models Replicated: Don And Abby, Jan. 8, 01, Day4
They started a new one at 22:34.

Driving question or scenario (according to student pair's class presentation): What affects DO?
Objects: 1. PLANTS, normal, description: affects DO 2. DISSOLVED OXYGEN, normal (a bug icon), Desc: dissolved oxygen in water. 3. WATER FLOW, normal, Desc: rapid flow increases DO 4. PRECIPITATION, custom icon (the sun image), normal, Description: the more water increases rainfall which increases the speed of rapids. 5. ANIMALS, custom icon (bug), normal, Desc: the more DO the more animals because the more plant, then the more life could support from. 6. TEMPERATURE, custom icon (sun and cloud), normal, Desc: Cold water holds more DO and the warmer the water, the more plants?
Variables: 1. PLANTS –amount of plants, text, initial value: default, Desc: (No). 2. WATER FLOW—speed of water, text, Initial value: default, Desc: faster the water goes over rocks, the more interaction between air and water. 3. PRECIPITATION -the amount of precipitation. Text, default value. Desc: more rainfall, the more water. 4. ANIMALS-the amount of animals in water, text, initial value: a bit lower than medium, Desc: the more animals, eventually the less DO. 5. TEMPERATURE—temperature of water, initial value: lower than medium, Desc: the higher the temperature, the more plants. 6. PLANTS —the amount of DO, text, Initial value: default, Desc: (No).

Relationships: 1. (As) TEMPERATURE—temperature of water (increases) DISSOLVED OXYGEN - the mount of DO (decreases)(more and more) (BECAUSE) cold water holds more DO. 2. (As) TEMPERATURE—temperature of water (increases) PLANTS -the mount of DO (increases) by more and more (because) plants like warm water. 3. (As) PLANTs-the mount of plants (increases) DISSOLVED OXYGEN -the mount of DO (increases) by (more and more) (because) plants make DO. 4. WATER FLOW-the speed of water increases DISSOLVED OXYGEN-the mount of DO (increases) by (more and more) (because) the faster the water, the more interaction between water and air. 5 or 6., (As) DISSOLVED OXYGEN - the mount of DO (increases) ANIMALS-the amount of animals in water (Increases) (A little) (BECAUSE) animals need oxygen, more oxy 6 or 5., (As) PRECIPITATION -the amount of precipitation (increases) WATER FLOW—speed of water (Increases) (More and more) (BECAUSE) more water enter the stream

APPENDIX I.
Sample Process Video Transcript

* School: XXXX
* Teacher: Carol
* Unit/Exposure: Water Quality 1
* Period: C
* Student 1: Kelly
* Student 2: Nathan
* Day 1
* School year: 2000-2001
* Grade 7
* Date: 12/8/2000
* Tape No.: 140
* Video: Process
* Transcriber:
* Coder: BHZ

Note: This pair did not work on Model-It yesterday because they did not have much time.

[The previous part of the transcript was deleted intentionally given the space limit]

----PLAN
1831 Create new variable: STREAM-temp.
Nathan asks Kelly if it is OK if he uses abbreviation.
Kelly says it fine "I think that it is just a matter that we know what it means".
When typing in description, Nathan suggests to put "low temp equals high D.O"
(Ss use their own words--abbreviation to describe what they mean)

1940 Researcher: did you save?
Students: no. Thank you, thank you very much.
Then Students save the model name as "NAB+ Kelly ".

2040 Create new variable: STREAM-turbidity, text, initial value: medium
Description: (could not been seen).
Kelly suggests pH and conductivity.
Nathan: what are they affected by and what they affect, though?
He then suggests that the parking lot can affect pH because of the oils.
Kelly adds that parking lot can affect conductivity because of the salt.
Nathan then further suggests that pH does not really affect anything but it is affected by something else.
Kelly asks if they should include pH.
Nathan says yes but they can just put pH without description.
New variable: STREAM-pH, text, Initial value: medium, no description.
New variable: STREAM-conductivity, text, Initial value: high, no description.
Kelly: we had high conductivity, very high, didn't we?
[Ss are making connection !!!]

—-Build
2200 Nathan first arranges the icons as a circle first.
Nathan says that the # of cars will affect conductivity.
Kelly further suggests that it will also affect pH.
After connecting "# of cars" and "conductivity".
Nathan reads the verbal description on the relationship editor.
Kelly suggest the degree should be "a lot" because there is a lot salt but Nathan suggests " a little" because "it's far away".
Create new relationship: As PARKING LOT-# of cars increases STREAM-conductivity increases a little BECAUSE salts on the road/parking lot = higher cond.
[Again, they use abbreviation]
When Nathan tries to make the next relationship, he says they do not know how "# of cars" affects pH.
Then he reminds Kelly about anti-freeze, Kelly checks the piece of paper again and says the pH value of anti-freeze is 9.
Nathan further suggests that there is not too much anti-freeze.
Create new relationship: As PARKING LOT-# of cars increases STREAM-pH increases a little BECAUSE anti-freeze...
Nathan suggests to connect the # of leaves and turbidity.
He then says "anything seems to be affected by a little".
Kelly says "no, Leaves affect turbidity a lot".
Nathan agrees.
Create new relationship: As TREES-# of leaves increases STREAM-turbidity increases a lot BECAUSE more leaves will stir...
Ss were surprised when they see the change on the graph when use "lot" as the degree of change.
Nathan looks at the little square and Kelly explains that it denotes relationship and degree.
Nathan suggests that the location of trees will affect the # of leaves.
Kelly agrees, but Nathan reject the idea and suggests that the size of the tree will affect the number of leaves.
Create new relationship: As trees-the size of the tree increases TREES- the # of trees increases more and more BECAUSE the bigger the tree the more the leaves .
Kelly: So size would affect the trees and the shade. We can do it tomorrow.
Nathan then save the model again.
Create new relationship: As STREAM-size increases STREAM-temp decreases a little BECAUSE the deeper the lower the temp.
Nathan thought about "less and less" because when the size is larger to a certain point, the temperature...Then he could not go any further so that he gives up.
Nathan moves his cursor around the variables and tries to make the next connection.
Kelly says it seems they have done the # of trees and the # of leaves,
but Nathan says that's the size of trees.
Create new relationship: As TREE-the # of trees increases TREE-the # of leaves increases a lot BECAUSE...
[Ss seem to have some variables that are similar].
Nathan tries to use "the location of trees".
He suggests that TREE-the # of trees affect turbidity.
Kelly agrees.
Create relationship: As TREE-the location of the trees increases TREE-the # of leaves increases a little BECAUSE the closer the trees to the stream the more chances that leaves will fall into the river.
[It's a clear argument, how about the quality?]
Create new relationship: As TREE-# of trees increases STREAM-temp. decreases a

little BECAUSE the more trees the lower the temp.
Ss create a reverse relationship between TREE-# of trees and STREAM-temp. but get a warning of "relationship cycle is not allowed".
Ss do not understand what does it mean.

3327 Kelly asks the T what does it mean.
T says that they cannot have a loop.
Ss comment that it is not that important.
Kelly moves the cursor around the variable icons to check if they have had relationships that they prepared.
Nathan suggests the following relationship:
Create relationship: As TREE- size of trees increases STREAM-temp. decreases a little BECAUSE the bigger the trees the lower the temp.

3442 Nathan: ok, save and quit.
Tomorrow you will type, ok?
Ss save and quit.
3500

APPENDIX J.
Sample Classroom Video: Teacher Instruction Transcript

* School: XXXX
* Teacher: Carol
* Unit/Exposure: Water Quality 1
* Period B
* Day 1
* School year: 2000-2001
* Grade 7
* Date: 12/7/2000
* Tape No.: 129 HK068
* Video: Classroom video
* Transcriber: R. Myers
* Coder:

(Note: T: = Teacher; S: = Student; S-G = Student Girl; S-B = Student Boy)

[Random talking]

T: Take the highlighter with you and highlight keywords and directions and what happens with that is that they were able to make sure their answer matched and they were following exactly what they should be doing in the question and that is exactly what you should be doing.

Okay so those are some things for you to keep in mind for tests but actually you did, you're doing well, you know so we're really, really excited.

So I just have to do that last sheet and you'll have them back in your hands.

Also with the number as soon as I make copies of the grades I'm going to give back, the majority of them are quality booklets tomorrow.

I have just a few more that I'll get done and you'll get those on Monday.

But at that point I'm just going to make a copy so that this way you will take those home, you'll have your parents sign them because I want them to read over the comments with you and then I want them back when you come to take the final, mid-term exam so I can keep them here over the holidays and then we have them when we do our Winter data collection, okay?

Because I can't tell you when we don't do that how many seem to get lost in a room over Christmas or the holidays and I don't want that to happen, okay?

Because you need to have those to speak from and _________.

As I told you we are going to do something different today.

I'm going to introduce you briefly, the reason I'm going to do it briefly is because you all play video games and all kinds of programs that you take tutorial, some of you, and work with them like Nap Blaster, Map World, and all these different things.

The thing is that part of the challenge is to figure out how something works.

So what I'm going to do is give you the bare necessities and then you all are going to go to the computers and you are going to build a model.
This computer we're not going to use because it turns purple and pink.

It's not dieing but the gentlemen that comes in and ______ the computers is going to be coming in tomorrow and he has to look at this.

The screen flashes purple and pink.

It happens all the time and I'm afraid if you use this, whatever you put on here is going to be difficult, or you may lose it.

So we have ______ computers, we have what ______, right?

I want Jessica and Amelia will go to this one, and Sam and Elizabeth you'll go to the last one, okay?

Open up your comp books, you need to take some notes.

And you will date it, what's today's date?

After you date it, today's date December 7^{th}, we are going to put in next to it, underneath it Model-It.

Model, like this.

Okay, and this is a program where we can construct a model that represents our understanding of water quality, we're going to do it around water quality.

Now we are going to start right now as we're learning how we use Model-It and building relationships.

We are going to build a simple model, okay.

Today, you will have tomorrow, and Monday, okay we're going to present.

Then Tuesday, Wednesday, and Thursday we will review.

How I want you to look at this Model-It not as something different, not as something on top of but in this case it will be serving for you as a review of something for the final, right?

Because we have been working with water quality, it will be on the final.

This perhaps will be a model that will help, okay, redefine or fill it in even better in your mind what that particular part of water quality is.
[Sample teacher's lecture ends here.]

T: Now, when you build your model I want you to come up with a question.

Thinking about the strengths, what kind of object do you think you would want to, what kind of physical feature do you think you would like to build a model around?

Who can think of something right now, real quick.

S-B: Waterfall?

T: James, a waterfall, very good.

If a waterfall is my object, James, okay.

What kind of question could I come up around this waterfall?

S-G: What causes the waterfall and _________?

T: Okay, we know what causes a waterfall but based around, why would you pick waterfall anyway?

What does it have to do with water quality?

S-G: ________ and water quality?

T: Okay, how, and specifically what?

S-G: It can change the temperature because it's moving faster ________.

T: Sure, so how could we build a question around that?

How does…

S-G: How does the waterfall change the _______?

T: Sure, or we can just say in general, so how does a waterfall

S-G: Affect the quality of life, even?

T: Well we want to remain specific.

So how does the waterfall affect the quality of water or you can put how does a waterfall affect the dissolved oxygen level in the stream?

So let's just say these are some questions that we could have.

So we have a waterfall, now what are some of the measurable traits of the waterfall?

What are some of the variables?
[Sample teacher-student conversation ends here.]

Note: T= Teacher; S= Student; G= Girl; B= Boy

APPENDIX K.
Sample Classroom Video: Student Pair Class Presentation Transcript

* School: GH
* Teacher: Alice
* Unit/Exposure: Water Quality 2
* Period A
* Student 1: Cathy
* Student 2: Shirley
* School year: 2000-2001
* Grade 7
* Date: 3/21/2001
* Tape No.: CV103
* Video: Classroom video
* Transcriber: Andrea
* Coder:

(Note: T = Teacher)
0100 Teacher asks Cathy and Shirley to prepare their model
[Students presented using their own machine.
Teachers and others sat around the computer and looked at their model when they were talking and manipulating their model]

0322 Cathy: Stream died, our stream is a little bit messed up at this moment.
T: Okay, let's start. Just a reminder, you're going to start with your driving question, you'll go through your model, the rest of us are going to watch and listen and look carefully and what is it that we're looking for specifically?
Cathy: What is our driving question?

Shirley: (Look at the researchers' date collection equipment) We forgot to record it.
[Students adjusted the data collection equipment so that their presentation could be recorded.]
Cathy: No, she's recording it… someone pushed the button,
[With the help of the researchers, the machines are working again.]

Cathy: There we go.
Hi. Our driving question is what are the causes and affects of what…
Shirley: thermal pollution [laugh].
Cathy: Okay these are objects, kind of obvious.
People, factories, cities and causes and the reason there are two people is because this family, this family is a polluted family and this guy is a one who could be building a factory.
So they're like different, represent different things.
S: You made the same object in two variables.
Cathy: Yeah we didn't want to do that. [Inaudible].
(Talk to Shirley: you can explain this.]
Shirley: Okay, well our web is this patch here (pointing on the screen0,
these plants will dies and they cause decomposers to come and the decomposers will change the temperature which will affect how much thermal pollution and um,

T: If you're going to mainly work through this one can you tell us about he graphs going up and down or?
Shirley: Okay, like the sun shines on the street and that could affect thermal pollution if it shines more in one area then another. And the what season it is affects like,
[Talking all together] click on relationship.
Shirley: Okay, what season it is increases how much thermal pollution because [Opening relationship editor and found something unexpected]...
Cathy: okay, we had to add things the relationship, yesterday we were trying to make some of the relationships.
T: Okay, so tell us [inaudible].
Shirley: Okay, because like in one season there might be like snow or something and the snow runs off on a certain hill causing that water to be colder than in another area that isn't on a hill or something. And like,
Cathy: Like the air temperature, like if there's rainfall,
Shirley: And that'll make it colder
Cathy: If it is shining and rain falls sometimes in the winter also the sun is shining but the only way to explain that is does not cause thermal pollution from sliding to the stream is because the rain is not hot because its winter.
Shirley; and there is no hot sidewalks outside.
Cathy: Yeah.
T: You can also talk.
S2: Sorry.
Shirley: Okay, and then the weather from here to over here (pointing on the computer screen) is how much it rains and if it rains a lot and it's really hot outside at the same time like the rain will bounce off the hot sidewalks and run off into the stream causing the stream to heat up in that particular area.
Cause like if there are no hot sidewalks it'll just rain but like sometimes it'll be hot rain if its like hot outside so the rain will like enter the stream just by falling.
Cathy: And the family, how much the family pollutes its not just polluting its like, like if the family is having picnic by the streams like more dirt's going to fall then like walking around the street, like you know like, we talked about that like....
Shirley: Like...how [inaudible] could affect turbidity.
Cathy: Yeah and so and that affects how much turbidity there is,and how much turbidity there is affects how much aquatic life and fish eggs there are because they smother it.
Shirley: (pointing on the screen) It also affects the thermal pollution because dirty in the water cause the water to heat up because of the sun light.
T: And just when you're doing a really nice job talking about how it affects this and affects that, but you're not telling us exactly how it affects it.
Does it affect it in a positive way or does it affect it in a negative way?
Cathy: negative.
T: So just make sure you interject that part.
Cathy: Okay because well the family is not good because they're polluting and that's creating or not polluting they're like around the stream which is creating a erosion.
Shirley: Well, like it depends because if there's not much family when your building it or testing it or whatever, then there aren't much turbidity.

[Students have different explanations for the same phenomenon.]
Cathy: Mm, hmm, and, and then (Cathy looks at Shirley seems to seek support and Shirley smiled back), like this person is building the factories and that's not good and then the factories...
Cathy: (factories) Are dumping chemicals in the stream which causes the water in the area where they're dumping to have a causes the stream to heat up, which would cause a difference in the temperature between that and another location. Okay.
Cathy: That's all.

0811 T: Now, again you might want to just test part of the model and bring up the meters for the other part of the model.
Cathy: No, that's okay.
T: you think that you can get them all? [inaudible].
Cathy: (Shirley was opening the meters on the test mode)
Yeah [inaudible]. We can just move the dependent variables.
T: Okay, so as you discuss talk about these as well....
Shirley: Yucky.
T: The colors are all random.
S: Oh, we had it. [Inaudible].
S: I'm like look yucky.
S: A raccoon got in my trash yesterday.
Shirley: Well thank you for sharing.
S: There's like trash all over.
[Talking over each other about raccoons].

T: We want to be able to see, so you have only independent variables up there?
Shirley: Yeah, the dependent variables are down there (blocked by the graph area).
Shirley: Ok, A lot of plants are dying and there are a lot of people and it is,
T: [teach asks other students to listen].
S: Oh Leslie.
Cathy: It is fall and the family is polluting a lot and there's a lot of rain,
and the oh no, the season should be and the and,
[Cathy realizes that her explanation has a problem...]
T: Which ones the water quality? What color?
Cathy: This?
Shirley: No, that's the sun, go down.
Cathy: No, water quality is all the way, [inaudible].
T: yeah, we should be able to see some of the dependent variables.
That's when you might only show us part of cause we want to see how when you do something else with the independent how the dependent ones are affected right?
Shirley: How much thermal pollution is yellow.
T: And then you have thermal pollution hooked to water quality?
Cathy: Well yeah.
Shirley: Yeah.
Shirley: (Look more closely) Well, no.
[People in the class, Laugh]

Cathy: Okay, um, yeah, so.
T: I think you to get a 25 inches monitor (in order to open all the meters].
S: Get a big screen TV.
Cathy: Basically now there's a lot of turbidity but ...
Shirley: The thermal pollution is medium because what season it is? is summer.
Shirley: oops you made a mistake.
T: Well tell us a mistake [inaudible].
Shirley: (pointing to the meters) Well what we did is that should be the lowest season so that should be like winter, or like spring and spring/summer/fall should be in the middle and like summer should be at the top.
[Shirley found anomalies, but Cathy seems just want to finish it.]
T: Okay, in terms of being the highest?
Shirley: Only we [inaudible].
Cathy: Okay so there we go so that works.
So that's all.

T: Well I'm still not quite sure,
I'd like to see some of the relationships more because I don't, you're very familiar with what it says from a distance its hard for us to read so you kind of have to talk us through it. When this you know, so,
Cathy: Well, when the plants and decomposers ,
when there's a lot of plants and there's a lot of people, then the turbidity level is high.
When the family is not polluting quite so much, then the turbidity level gets low because the family is not polluting really big.
[Inaudible] and what it is.
And if the season is bad then the turbidity is going to be bad.
Shirley: That's good though because we made a mistake.
So just close out season and forget about season.
[Again, Shirley has different idea from Cathy.]

Cathy: And if there aren't very many people, then the thermal pollution is going to be OK..
T: Thermal pollution will not [inaudible] if there is not many people?
Cathy: I mean [inaudible]...lower.
If there aren't as many plants. then what should be happening (look at the screen)...
if the sun is not shining...
Shirley: [inaudible].
Cathy: What again?
Shirley: Those little, circle, ok, let go back to plan (mode).
Shirley: Okay move that simulation back up.
Shirley: (In plan mode), Okay we chose this because weather and..
Cathy: this is the weather that if there's a great deal of turbidity that if there is a sun causing pollution.
And this is the sun. Kind of obvious hopefully,

and these are plants. This is aquatic plant life that will cause decomposers to come and decompose the plants. This process is called the eutrophication that uses up dissolved oxygen.
When there is not enough dissolved oxygen that means...
oh, well our thing was erased in the middle and we had to redo them and [inaudible].

1330 T: So what causes eutrophication?
What was the beginning part of that?
Cathy: Um, that will cause decomposers to decompose the most plants after they die.
T: Oh.
Shirley: This is turbidity kind of cloudy and
Cathy: We couldn't find any of them.
Shirley: Oh okay. And then this is our family because they're actually mom and a dad and a little kid.
Cathy: And family can pollute and increase the level of turbidity and cause more thermal pollution.
Shirley: And this is a person
Cathy: Who would build a factory.
Shirley: This is a person who could build a factory.
And this is the factory that could put hot water in the stream.
And then this is the season because it has like the sky that you could see clouds [inaudible].
Cathy: The seasons change and that changes the level of thermal pollution.
Shirley: And this is our aquatic life and the [word].
T: Oh okay I didn't see that when you test it.
Did you put that up on your testing?
S: Yeah and its because of,
[Talking over each other]
Shirley: Yeah. And this is because of...We couldn't [inaudible] but [inaudible].
T: What relationship did you have in terms of the aquatic life and fish eggs.
Shirley: This is our [inaudible] stream.
T: It's getting worse and worse or is it above?
Cathy: And this program isn't...
T: SO tell me about the aquatic life and the fish eggs.
Shirley: Well like with the aquatic life gets like to be a lot there's the turbidity smothers their fish scales and then they can't survive in certain temperatures if the thermal pollution's too high. And,..
T: SO there are two things in that?
Shirley: Yeah. And so you want to make sure that they can survive.
T: So animals survival in terms of temperature?
Cathy: MM, mm, well, I didn't, we did not have that.
What I thought we were doing was that turbidity is [inaudible] the turbidity is smothering the fish eggs and causing the fish [inaudible].
And that's about all.
[Again, Cathy emphasized "I" instead of we, and shows her impatience again by saying "and that's all."]

1530 T: (talks to all the other students) Okay so you can look at all the causes, so they have all the causes?
S: I think they should have pavement and sidewalks and stuff like that in there. Cause they have like the seasons directly affecting water quality and like the sun directly affecting it. I think it'd be better if it had pavement.
T: Okay so you talked about the reasons really well, you have a good understanding. Your model could have that intermediary with the seasons go to the pavement and the pavements go to the water quality instead of going straight there.
S: Yeah also cause the sun doesn't exactly like shine on one exact spot, it shines like in a broad area.
S: And so does seasons. Unless you have pavement, [inaudible].
T: Alex?
Alex: They don't have like, water quality....only thermal pollution.
[Great, Alex pointed something important that is missing!]
T: Well, then, you have thermal pollution?
Shirley: well, we only have in the thermal pollution.
I mean we have, we should add water quality but when we have like thermal pollution's say, like, how much thermal pollution there is in the water quality?
T: Mm, hmm, so maybe so you could have a 2nd variable see thermal pollution as one and that goes to the quality of the water.
Although when you talked about it that's how you did talk about it.
And so any other thing in terms of, we have several new causes any affects?
What about the affects, water quality is one?
Cathy: And the aquatic life.
Shirley: and fish eggs
T: Now you have eutrophication on your model and when Christopher and Simon were revising their models yesterday we had a little discussion about that do you want to share that?
Simon: Um,
Simon: Yeah eutrophication usually comes from having like high nitrate and phosphorus not really from thermal pollution of some kind.
T: Although the way you've represented it you've done this accurately because you were talking about the plants dying and then adding nitrogen and phosphorous whereas the way you were talking about it we were talking about it, it would be thermal pollution directly that would cause what?
Simon: Ah,
T: [inaudible]. The excess plant growth.
Okay. Nice.
And we know you lost some of it from earlier.
Cathy: Yeah that one is as good as this.
T: Alex, Are you right?
I'm sorry you are ready?
Alex (Female): Yeah I think so.

1811 End of the presentation

APPENDIX L.
Sample NUD*IST Report of Modeling Practices of Process Videos

```
Q.S.R. NUD*IST Power version, revision 4.0.
Licensee: N40E.

PROJECT: 1BH_DissertationProject, User BaoHui Zhang, 9:07 am, Mar 10, 2003.
++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++++
Margin coding keys for selected nodes in document WQ1_PV142_SP&CF:
A: (3 1 1) /Modeling practices/Initiating/Stating goals      H: (3 2 4) ~tices/Analyzing/Deciding the course of action
B: (3 1 2) ~deling practices/Initiating/Discussing object    I: (3 3 1) ~ctices/Synthesizing/Elaborating relationships
C: (3 1 3) ~ling practices/Initiating/Discussing variable    J: (3 3 2) /Modeling practices/Synthesizing/Predicting
D: (3 1 4) ~ practices/Initiating/Discussing relationship    K: (3 4 1) ~practices/Evaluating/Critiquing-Interpreting
E: (3 2 1) ~odeling practices/Analyzing/Specifying object    L: (3 4 2) ~ng practices/Evaluating/Identifying anomalies
F: (3 2 2) ~eling practices/Analyzing/Specifying variable    M: (3 4 4) ~g practices/Evaluating/Carrying out solutions
G: (3 2 3) ~g practices/Analyzing/Specifying relationship    N: (3 5 1) ~eling practices/Searching/Seeking information

+++ ON-LINE DOCUMENT: WQ1_PV142_SP&CF
+++ Document Header:
* School: GH
* Teacher: Alice
* Unit/Exposure: Water Quality 1
* Period A
* Student 1: CF
* Student 2: SP
* Session 3
* School year: 2000-2001
* Grade 7
* Date: 12/11/2000
* Tape No.: 142 (39 min.)
* Video: Process
* First Transcriber: HK WU
* Second Transcriber: R. Myers
* Third Transcriber: BH Zhang
* Coder:

+++ Retrieval for this document: 509 units out of 509, = 100%
++ Text units 1-509:
                                                                  1
0000 SP read a sheet that tells their identities.                 2 A
Today's task is to see if they need to make changes.              3 A
CF controls the mouse and SP types.                               4
SP chooses "JASON" instead of "Water Quality" unit when opening.  5
CF says that they are testing "JASON".                            6
SP thinks they saved their file in a wrong place.                 7
They spend some time on finding their model.                      8
SP has to use search function to find their model.                9
Open their file.                                                  10
No images because they opened the "JASON" unit.                   11
SP goes directly to test mode.                                    12
                                                                  13
-----------TEST                                                   14
0257 SP: we found it!                                             15         H       N
```

APPENDIX M.
Sample Data Set for Generating ER Chart (PV146 ModelingActions)

A	Plan_CreatObj
B	Plan_DeleteObj
C	Plan_ModifyObj.
D	Plan_CreateVar
E	Build_ModifyVar
F	Build_DeleteVar
G	Build_CreateRel
H	Build_ModifyRel
I	Build_DeleteRel
J	Test_CreateMeter
K	Test_MoveMeter
L	Test_AdjustMeter
M	Save
N	TPR_Intervene
O	Off-task
P	Pause_Rearrlayout
Q	Dis_ToolScaf
R	Other-Actions
T	TechProblem
S	Start

12/8/2000	10:00:00	AM	r
12/8/2000	10:02:00	AM	r
12/8/2000	10:02:16	AM	f
12/8/2000	10:03:10	AM	f
12/8/2000	10:04:06	AM	f
12/8/2000	10:04:50	AM	f
12/8/2000	10:05:25	AM	r
12/8/2000	10:05:30	AM	a
12/8/2000	10:05:30	AM	n
12/8/2000	10:08:25	AM	c
12/8/2000	10:09:46	AM	c
12/8/2000	10:11:59	AM	r
12/8/2000	10:12:10	AM	f
12/8/2000	10:13:03	AM	f
12/8/2000	10:15:00	AM	f
12/8/2000	10:15:48	AM	f
12/8/2000	10:16:30	AM	f
12/8/2000	10:17:09	AM	n
12/8/2000	10:17:22	AM	r
12/8/2000	10:18:05	AM	k
12/8/2000	10:18:05	AM	n
12/8/2000	10:20:50	AM	k

...

APPENDIX N.
Sample Process Video Summary according to NUD*IST Report and Event Recorder (ER) Chart

* School: GH
* Teacher: Alice
* Unit/Exposure: Water Quality 1
* Period A
* Student 1: Charles
* Student 2: Simon
* School year: 2000-2001
* Grade 7
* Date: 12/11/2000
* Tape No.: 133
* Video: Process video
* First coder: EF
* Second coder: BH

1. Modeling actions:

This second day modeling lasted for 32 minutes. Students first created two more objects: PEOPLE and ANIMAL adding on the one object: STREAM they made last time. They then created 5 variables. Then they create 6 relationships, they was not able to create another one because they program does not allow feedback loop.

They then test the model. They learn how to test the model earlier than the students in B and C period because the teacher in this. A period shows students the whole constructing and testing on day1. They had a little bit difficulty in opening the meters for testing but they found how to do it by error and trial. They were only able to test the model for a short period of time, and then the class was over.

[The build-in scaffolds allows students to create a model although they might use different order, which might not be allowed, such as when they redefine the relationship, the "because statement" they typed disappeared. They could miss the variable description but could still create the variable.]

2. Modeling practices

Students did not asked their driving question and there was no way to find out why they made the decision about what to build in the model. It seems very likely that it is because they have planned the model because that was the homework of the last class. Their decisions of what to build in the model seem to be made without much discussion except for two relationships.

Students seem to be planned because they purposely search for images. Since students did not choose "water quality" unit when opening Model-It, they do not have the dragonfly image so that they use an blank icon for their object: ANIMAL.

0419 Simon: Alice, are there any animals or something?
The teacher and a research come.
Teacher: there is a dragonfly…
Researcher: on the palette.

Analyzing shows a process of making sense. The analyzing practice seems to be influenced by the scaffolds of the modeling program and teacher's intervention. Students made constant decisions about what to do next. Teacher also intervened frequently during the class period. Students seek information when they need an image for animals using the modeling program. The following excerpts show how do they provide descriptions and assign meanings to their variables.

0813 ...
(They then discuss the description.)
Charles: The variable is (People) many people.
Simon: Old people?
Charles: Big people. Description?
Simon: Fat people.
Charles: People dump chemicals.
Simon: (while typing)...people...Have come to the park and...
Charles: Have come to the parrrrk?
Oops, here we go.
Simon types the description in: people who come to the park
and dump chemicals into the water.
****
1137 Charles: so that other people want to make...
(He thinks about having another variable for people)
Charles: Variable...People...Go! (Charles seems to wake up Simon when he was stuck.)
Simon: Oh!...What am I supposed to write?
(Again, Simon does not know what to write for the variable name)
Charles: the variable, we have to write the variable for the people,
how they affect the animals....
Do we have to make a variable for conductivity?
Simon: Wait...for the animals?
(While Simon is thinking)
Charles: they hunt animals.
Simon write "hunt" in the variable name box.
Simon: okay, hunt is a variable or eat (giggles)....
Simon types in some description...
(Simon seems not confident about the variable name: hunt).
Charles:...I dig it. The variable???...
They are pretty good variable!
New variable: PEOPLE-hunt. Initial value: default.
Description: people hunt and eat animals for dinner.
They don't change other default values and clicks "OK".
They continue reminding each other about spelling.
[Ss seems not to be serious because they are not sure if they are write
but they have to do something in order to make the model.]

Students discovered an anomaly using testing, which is great. However, they seemed to have no intention to find out what was wrong.

----------TEST
2825 Resize the simulation graph.
Charles: we don't have a graph.
Simon: it sucks.
They are still clicking around.
Accidentally, they click on a variable and find out how to open meters.
[They figured out how to test by trial-and-error testing!]
Charles: oh, that's what we're supposed to do.
They open all meters.
Charles: now we play.
Charles click on play and color lines appear.
Simon: well, pretty good! The yellow is...
Charles: actually they are all the same (meaning that all the graphs are parallel because he points the cursor there.)

2906 Charles: What happen if there is less people?
[Charles is predicting and testing his hypothesis!]
They play simulation and change meter values.
Simon: ...more people kills more waste....
Charles: see the green (line)...
Simon: that's people get more waste, and...more...water quality.
Charles: Now what happens if (moving the cursor around the meters).
They are all dependent on people.
If there's tons of people,
Whoa, bad, there's more people that hunt less animals.
why this is not changing ?
Charles points the cursor to the meter with brown color.
(He tries to change a dependent variable.)
Simon: no, you can't change.
Charles: no, because it's all depending on this
(pointing to the yellow meter that represent PEOPLE-many people).
Charles: no, wait, we have backwards.
Because if there is less people, why is the conductivity going up?
[Charles discovers an anomaly.]
Simon: it's going down.
Charles: wait, so...see this.
That (SREAM-conductivity) should be high.
Simon: because there are less animals, because more people hunt.
[The reason that makes less people, higher conductivity is because they have a hunt variable between people and animal.
Less people, less people hunt, more animal waste,
so higher conductivity.]
(Students were puzzled about the testing result that
when there are less people and conductivity goes up,
which seems not right.)

Charles: so weird...wee.
Charles enlarges the graph area and look at the simulation.
Charles: this is awesome
They think the program is cool.
However, students do not have the intention to find
why they got unexpected test results.

Two times at least, Simon go to the "because statement" first before creating a relationship (1703-1812).
1703 Charles connects PEOPLE-many people and OUR STREAM-conductivity.
Charles: so people affect the conductivity, because people...
Because people...
(Charles seems to be thinking and also asking Simon for the because statements.)
Simon: because p...
[It's interesting that this time Charles does not defines the relationship
and relationship type but goes directly to the because statement
so that this relationship seems to be reversed as it should be.]
When Simon types in the statement,
Charles is moving the cursor and seems to look at the text description on the top.
Charles: because people...
(typing) dump different chemicals into OUR STREAM.
Relationship: (As) PEOPLE-many people (increases)
OUR STREAM-conductivity (increases)(about the same)
(BECAUSE) people dump different chemicals into our OUR STREAM.

1735 Charles connects PEOPLE-many people and PEOPLE-hunt
Charles: then the people will affect how many people hunt...Da...
New relationship: people--> hunt,
Charles: because more people more people hunt.
Charles types in the description.
Again, Charles goes to the because statement directly without defining
the relationship first.
Charles: (Pointing his cursor on the graph and moves along the slope)
should it go up just like that?
Simon does not respond.
(Simon has been slow in thinking and giving feedback)
Charles: no, I think it should
Charles changes the relationship type to less and less.
Charles: more like that.
Charles moves the cursor along the graph line.
Charles: Because I mean more and more people come and it'll be
so crowded and the hunt just begins down.
Simon: right.
Charles: Ok, cool.
Click on okay.

Relationship: (As) PEOPLE-many people (increases)
PEOPLE-hunt (increases)(more and more) (BECAUSE)
more people more people hunt.

3. Metacognition

They are becoming more aware of what they should do overtime, such as that they have to define the relationship before typing the "because statement."

4. Modeling knowledge

Simon keeps asking how to name a variable (0813). Charles seems not to have a fixed definition either. The following is an example when they did their best to make sense on how to use the program.

1022 Charles: How do I get a variable to this (for animal)?
[This is a utility problem.
They don't know how to create a variable associated with a specific object they want.]
Then they realize they can change the object in the editor.
They set the object: animals.
Simon: what am I supposed to write?
(He doesn't know how they should name the new variable.)
Charles: this is animals (giggles).
Charles: animal waste affects the conductivity.
They name the variable as animal waste, text, high/medium/low, medium.
(Their DQ should be something about conductivity.)
New variable: ANIMAL-animal waste, text, initial value: default (medium)
Description: the animal waste affects the conductivity of the OUR STREAM.

5. Collaboration

Students call each other's nicknames. Simon calls Charles "Ford".

It seemed that Charles proposed most of the decision. However, Simon seems to be more knowledgeable because Charles calls him as "Einstein." (PV142). Simon seems to have the power to make a final decision. Charles reminds Simon to move alone either by proposing an idea or actually so something when Simon seems to be stuck. Simon is a quiet and careful thinker while Charles is a quick thinker and active doer.

APPENDIX O.
Sample Cycle Summary according to the NUD*IST Reports and ER Charts

* School: GH
* Teacher: Alice
* Unit/Exposure: Water Quality 1
* Period B
* Student 1: Charles
* Student 2: Simon
* School year: 2000-2001
* Grade 7
* Date: December 2000
* Tape No.: 124, 133, 142 & 151
* Video: Process video
* First coder: EF
* Second coder: BH

1. Modeling actions:

This modeling cycle lasted for four days while the first day students only had two minutes to get started. They create an object STREAM and the class is over.

They seem to have something their mind because they purposefully search for images. They first created all the objects, then variables, then relationships, and they were even able to test the model at the end of their second day.

Students were supposed to self-evaluate their model according to a checklist their teacher provided on Day3. They have minor revision and expansion of their model, but lost this model for a technical problem.

The fourth day they modified and expanded their model based on the model from day2 after testing it first. The ideas were basically from Day3. They finish a simple model with clear pattern.

2. Modeling practices

The modeling actions of creating objects, variables and relationships were similar to the way that the teacher demonstrated the use of the program.

Planning seems to be a continuous process because students have to make decisions abut what to build. They have frequent discussion about what to have in the model.

Analyzing might be suggested by teacher's demonstration because they usually create variable(s) right after they create an object, which is similar to the way the teacher did during her demonstration of using Model-It. It is still a process of making sense of both the program as well as modeling and thinking about what they have learned of the content knowledge.

Synthesizing seems to be weak because there was a loose integration between the driving question and student model. Students seldom mention their driving question. They had some basic ideas about water quality and animals, but they finalized their driving question until before they presented their model. Furthermore, they modified their driving questions to include ANIMAL instead of only PEOPLE by reviewing their model. There was no connection to their investigation, however.

Evaluating seems to be superficial because even they went through the teacher's checklist, they did not have any specific comments about their model except keeping saying "yes" or "no" to defend their model. It seems that the weak synthesizing ability is related to their weak modeling knowledge, such as how to evaluate a model.

Publicizing with teacher's or more knowledgeable others' comments and feedback helps students to improve their model. Further, it is an opportunity for students to think through their model in order to be able to present the model to be understandable to others.

3. Metacognition

Students frequently make decisions of the course of actions. The teacher also provides supports to help students in deciding what to do.

They do not ask questions very much, though.

They do not use their booklet much although the teacher has reminded them and the whole class.

4. Modeling knowledge

Although teacher had a checklist for students to evaluate their model, they did it somewhat superficially because they almost made no modification to their model. Students seem not to know the purpose of creating a model and how to evaluate a model. For example, SP asks how to name a variable and write description and they seem to get used to this and write whatever they have.

5. Collaboration

Both students are engaged and there was almost no off-task activity.

As mouser and typer, they have never had problem collaborate with each other. SP follows the teacher's instruction closely, such as examining the model using the checklist, save…and this becomes the way that he "decides the course of action."

Students have a good rapport. They ask each other's feedback when proposing a decision. They call each other's nicknames.

APPENDIX P.

Sample Classroom Video Summary: Introduction of Modeling and Model-It

* School: GH
* Teacher: Carol
* Unit/Exposure: Water Quality 1
* Period C
* Session 1
* School year: 2000-2001
* Grade 7
* Date: 12/7/2000
* Tape No.: CV132
* Video: Classroom video
* Transcriber: R. Myers

The teacher was thorough in giving her plan of introducing Model-It. It would be in several steps in two days, not like they did in the first year that they spent a whole class introducing the basic concepts and demonstrate the use of Model-It.

The teacher mentioned that the university researchers need their feedback on the use of the program. Teacher gave an example of a change that was according to the feedback from students. Researchers had changed "factor" to "variable" to be more understandable and accurate.

According to the teacher, partners of the stream investigations would stay in the same pair or group because students were making water quality models to demonstrate their understanding. They were going to do modeling for several cycles this school year.

The teacher asked questions like "what is a model?" "what do you know about models?" "The following quotations were what the teacher introduced about the use of models "The physical representation, for instance we can use Nerf balls and a light bulb to represent the sun and the earth and how it would move around and what kind of things it would affect because we can't exactly go out there and change things around in the Universe, right?...But we can sort of mimic model what it is that happens and we can then begin to understand what exactly what is happening in nature."

"What can we do with models ...So models allow us to work with the representation that is out there and we can change it and see how those changes affect that model and how it works. And that's what's really cool about it."

The teacher then explained several definitions: object, variable, and relationship. "Objects are...the physical objects found in the environment...such as trees, stream... they are found in nature and they have some kind of measurable feature"
" Variables are going to be what are the specific traits about those objects that we want to see how it influences water quality, okay?" The teacher worked with students proposed some exemplar variables, such as "how many tree? " how many leaves of a tree?" "the size of a tree". A variable for a stream object might be "turbidity", "temperature" or "DO".

The teacher emphasizes that students needed to create a model around a question:

T: want you to build it around a question, okay?
So it may be in this case, how do trees affect water quality?
What is the many different ways trees affect water quality?

And then you'll think of all the objects and factors of something that affects, that can impact water quality and then you will find out why, like number of leaves decreases, number of dead leaves the water increases, the _______ turbidity increase or there might be direct relationships, there might be indirect relationships, all kinds of things.

...

Tomorrow we're going to spend 5 minutes showing you how you set up the relationship because the relationships between these, any between objects in the cause of that relationship.

You know, it's the number of leaves that end up in the stream it causes an increase in turbidity.

That causes a decrease in... it eats its own oxygen.
Or it causes a decrease in temperature or it causes an increase in temperature.
Those are all the things you're going to brainstorm.
And then all the other causes.

Now the teacher has introduced all the necessary knowledge to ask a question, create objects, variables. When the teacher demonstrated the use of Model-It, some students began to throw out their ideas and a lot of them included cause and effect relationships. When the teacher introduced variable editor, in the description box, she wanted students to think about possible relationships. However, there were few examples of the descriptions.

The teacher did not demonstrate how to create relationships during this class in order to reduce students workload in learning new things. This was a change from the first enactment last year.

Students then had some time to brainstorm their question, planned their models and then worked on computers to use Model-It. Some of students get several minutes to use computers, but most of them did not get a chance to use model-it

Note:

On the next day (12/8/00, CV138), the teacher reviewed what she taught today. After students created some objects and variables, she used a 8th graders' weather model to show students how to create relationships. It seemed that students understood how to create relationships because they were able to propose relationships that make good sense.

On the next Monday (12/11/00, CV147), the teacher showed students how to create meters and run simulation to test the model. She asked students to consider the following questions when testing the model:

1) Does the model answer their (driving) question?
2) Do the relationships make sense?
3) Does the graph work? What do you notice between independent and dependent variables?

It seemed that the teacher had guided students to go on the right direction when testing the model. However, since students did not have a complete idea about what a model would look like at that time, it seemed that this one time instruction was not enough because later students did not show explicit criteria for evaluating their models in a holistic sense, which means that they considered their model as a system.

APPENDIX Q.
Sample Classroom Video Transcript Summary: Modeling Session

* School: GH
* Teacher: Alice
* Unit: Water Quality 2
* Date: 3/15/2001
* Tape No.: 095
* Video: Classroom video
* Period: A

Over view: Today is cycle 2, water quality 2. Students spend the whole time (8:05-8:50) on the computers today. The teacher reminds student to test their model often. She gathers the three groups of thermal pollution to discuss the influence of seasons that students have not address near the end of the class.

The following are some teacher interventions and the time when they occur:

8:04
The teacher tells the class that they will spend whole time on the computers today.
The teacher suggests the three groups with the same questions getting together today or tomorrow.
Cathy prefers doing it tomorrow.
The teacher also encourages students to use their booklets resources and discuss their ideas with their partner(s).
The teacher asks whether the students have any question.
The teacher reminds students that causes and effects, model needs to be comprehensive and they should save often so that they do not lose their model in case of technical problem.
Then students go to their group's computer and start working.

8:10
The teacher reminds them to test their simple model first;
the students should not wait until the last minute.

8:16
The teacher reminds students to take turns in controlling mouse and typing.

The teacher gathers the three groups of thermal pollution to discuss the influence of season

APPENDIX R.
Sample Summary of Student Class Presentation

* School: GH
* Teacher: Alice
* Unit/Exposure: Water Quality 2
* Period A
* Student 1: Cathy
* Student 2: Shirley
* School year: 2000-2001
* Grade 7
* Date: 3/21/2001
* Tape No.: CV103
* Video: Classroom video
* Transcriber: Andrea
* Coder: BaoHui

1. Modeling actions:

This presentation lasted for about 17 minutes. Students started from build mode and then the teacher suggested them to run test and show the class how the model worked. There was not revision. Students also went to build mode to check the detail of some relationships by opening the relationship editors

2. Modeling practices

Students were required to tell their driving question. It was interesting that Cathy forgot the detail of their driving question and Shirley helped her. Basically the model students presented was aligned with their driving question.

Publicizing seemed to first allow the students to articulate their understanding of the causes and effects of thermal pollution as the driving questions indicated. Students were also exam and reflect on their model. For example, during the episode of 0811, Cathy realized that her explanation had a problem. They also found that they did not fill in a description box in another case.

Publicizing with teacher's or more knowledgeable others' comments and feedback helps students to improve their model. For example, teacher asked them to tell their driving question first; then the teacher asked them to test the model; the teacher also questioned whether the relationships had negative or positive effect.

Publicizing seems also to be an opportunity for other classmates to share their understandings. For example, at the very beginning a students said that they had two variables using the same object which he implied that Cathy and Shirley were wrong but Cathy seemed not to agree with him. Near the end of the end of the presentation, another student pointed out that they did not have a water quality variable for the water quality model. With teacher's help, students also clarified the meaning of eutrophication.

Students also showed basically accurate understanding of their content knowledge, such as stating the causes around their driving question and the most important ideas of temperature change (increase) as the effects of all the causes (e.g. hot seasons, chemicals, sun heated particles when there was big turbidity).

3. Metacognition

Students moved along with their presentation smoothly while also responding to teacher's and other classmates' questions. They collaborated and were aware of how they shared the tasks of presentation.

4. Modeling knowledge

Students seemed to be familiar with the concepts of independent and dependent variables because they learning how to arrange the meters and they understood that they were only able to change the values of independent variables. They could also test part of the model or example individual components of the model. For example, in build mode, they check individual variables and relationships. Their articulation of the causes and effect was clear.

5. Collaboration

This pair of students shared the tasks of presenting different part of the model. They also competed with each other occasionally. They did not hide their disagreement although the model was supposed to reflect their shared understanding. However, they also had good rapport so that they just looked at each other and smiled when they showed disagreement.

It seemed that the class has also formed a culture of sharing. For example, Shirley thanked another student for sharing who told the class that a raccoon got in his trash yesterday.

APPENDIX S.
Exemplar Model Critique Sheet of the Water Quality unit

Names of critics:______________________________

Name of Model:____

Model Authors:_______________________________

LIST OBJECTS:	ACCURATE FACTORS:	ACCURATE RELATIONSHIPS **(including independent and dependent variables)**
	INACCURATE FACTORS:	INACCURATE RELATIONSHIPS:
UNNECESSARY OBJECTS:	UNNECESSARY FACTORS?	UNNECESSARY RELATIONSHIPS?
MISSING OBJECTS	MISSING FACTORS	MISSING RELATIONSHIPS

Does the model accurately portray the driving question? Explain.

What do you like about the model?

How can the authors improve their model?

(Note: Spaces in the cells are reduced from the original two-page form.)

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