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# EXAMINING PROSPECTIVE SCIENCE TEACHERS' UNDERSTANDINGS OF THE ROLE OF MODELS AND MODELING IN SCIENCE WITHIN THE CONTEXT OF BUILDING AND TESTING COMPUTER MODELS OF POND ECOSYSTEMS

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Michael Joseph Cullin



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The thesis of Michael Joseph Cullin was reviewed and approved* by the following:

Barbara A. Crawford
Assistant Professor of Education
Thesis Advisor
Chair of Committee

Carla M. Zembal-Saul
Associate Professor of Education

James F. Nolan, Jr.
Professor of Education

Susan M. Land
Assistant Professor of Education

Patrick Shannon
Professor of Education
Coordinator of Graduate Programs
Department of Curriculum and Instruction

*Signatures are on file in the Graduate School

## ABSTRACT

Contemporary reforms in science education place an emphasis on students learning science as inquiry by reasoning about scientific phenomena. To be successful their teachers need to be knowledgeable of not only the important ideas of science but also the reasoning that led to the development of those ideas. one critical aspect of the scientific endeavor is scientific modeling whereby an unknown, inaccessible phenomenon or system is explored through the examination of a familiar, accessible entity called a model. Empirical research suggests that most teachers, both inservice and preservice, do not possess the kind of in depth understanding of the role of models and modeling in science necessary to support s students in model-based reasoning.

This qualitative case study examines the modeling understandings of eight prospective science teachers in a unique context. The prospective teachers participated in a seven-session instructional module in a science content course designed for prospective teachers. The module emphasized the role of models and modeling in science and involved field studies of pond ecosystems, explicit instruction on scientific modeling, and the capstone experience of building and testing computer models of the pond ecosystem. Data collection consisted of pre- and post-module questionnaires and semi-structured interviews, the models built and tested by the prospective teachers, and process-video captured while the prospective teachers built and tested their models. Data analysis led to the formulation of numerous assertions related to the prospective teachers' understanding of the role of models and modeling in science.

Five dimensions of modeling understanding were identified from the literature and served as the basis for rating the prospective teachers' understandings. Most of the prospective teachers initially held naïve views regarding models and modeling and expressed more scientific views, but not expert-like views, after the module. The models built and tested by the prospective teachers were assessed via a scoring rubric developed by the author. The models revealed little about the prospective teachers' modeling understandings. The models did however bring to light alternative conceptions about pond ecosystems held by several of the prospective teachers. Through analysis of the process-video data, the prospective teachers' modeling strategies and obstacles to successful modeling were revealed. The use of frequent testing of models was shown to result in better models. Obstacles to successful modeling included inadequate knowledge of the modeling software, software limitations, inadequate domain-specific knowledge, and inadequate modeling knowledge.

Implications are given for science education research, science teacher education, and science teaching and learning.

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# Chapter 1

# INTRODUCTION

## 1.1 Scientific Models and Modeling in the Context of Science Education Reform

Much of contemporary reform in science education is based in the premise that "Teaching should be consistent with the nature of scientific inquiry" (AAAS,1989, p. 201). One important and often overlooked aspect of scientific inquiry is modeling (J. K. Gilbert, 1995). The recommendations of the National Science Education Standards (NRC,1996) suggest that students not only learn science via inquiry, but that they develop abilities to *do* and understandings *about* scientific inquiry. Scientific inquiry includes the methods, activities, and progression of such that lead to the acquisition and development of scientific knowledge (Schwartz, Lederman, & Crawford, 2000). Building and testing models of natural phenomena (modeling) is one means by which new knowledge is generated in many fields of science (Hulse, 2002, personal communication). It stands to reason then that achieving the vision of contemporary science education reform requires teachers to possess well-developed abilities and understandings regarding aspects of the nature of scientific inquiry. These aspects of science include activities such as those associated with models and modeling integrated with knowledge about teaching and learning.

### 1.1.1 The Importance of Models and Modeling in Science

Humankind has always needed models for understanding the complex world in which we live (Catlow, 2000). Models are powerful tools. They guide explanation, interpretation, understanding, and discovery and enable scientists to generate predictions (Jungck & Calley, 1985). The process of modeling engages the imagination of the scientist through the actualization of thought experiments that are often impossible due to their complexity or impossibility by any other means.

A model of a phenomenon is a simplified imitation of that phenomenon that we hope can help us understand it better (American Association for the Advancement of Science, 1989). In model-based reasoning, a model is built and investigated in the place of a target (an object or phenomenon) that is inaccessible for some reason. Learning about the behavior of the model offers insight into the behavior of the target. Schank and Duncan (1997) described numerous activities in which scientists routinely engage that involve aspects of modeling.

> The application of statistics to a set of data in order to decide whether to accept or reject a hypothesis or to explore the data is modeling. The visual representation of data in order to discover relationships among variables and parameters or to support a hypothesis is modeling. The formulation of a system of differential equations with the aim of better understanding, predicting, or explaining the dynamics of a physical system is modeling (Schank & Duncan, 1997, paragraph 1).

Scientific models can be classified based on their form and purpose. Colella, Klopfer, and Resnick (2001) refer to illustrative, analytic, and simulation models. Illustrative models provide visualization of a scientific process or system. Analytic models are based on mathematical equations and permit the exploration of various scenarios. Such models generate solutions that predict behaviors of systems based on a given set of conditions. Simulation models are similar in many ways to analytic models. Rather than merely solving a set of equations though, the mechanisms underlying a phenomenon or system are identified and the simulation is permitted to run over time to see what happens.

In contemporary science research, computers are increasingly relied upon for investigating complex phenomenon, such as global climate change using simulation models. Computer modeling and simulation have changed the nature of scientific investigation by enabling researchers to pose new kinds of questions and explore phenomena in ways that were not possible just a short time ago (Vanessa Colella & Klopfer, 2002). In addition to aiding in the development of explanations of complex phenomenon, the predictions of such models can influence important decisions, such as whether or not the public will be safe from a nuclear waste deposit site built deep under a mountain. Nobel prize winning physicist Russell Hulse suggested:

> I am fond of saying that in fields where modeling is important, that the elaborate computer models which are constructed really have become the ultimate repository of knowledge - meaning that they are the place where knowledge is incorporated in a useable form. The models are used to test whether our knowledge hangs together, to predict new behavior, to explore new theories and concepts, and to design new experiments and/or experimental devices (Hulse, 2002, personal communication).

Models are a critical component of the scientific endeavor. It has even been suggested that science be defined as the process of constructing predictive conceptual models (S. Gilbert, 1991).

### 1.1.2 Science Literacy and the Role of Modeling

For some time, the ultimate goal of science education has been to develop a scientifically literate society. The term scientific literacy has been defined broadly.

Ultimately, a scientifically literate individual might be considered to be someone who finds science interesting and important, who can apply science to their own lives, and who can take part in the conversations regarding science that take place in society (DeBoer, 2000). For science educators, identifying means for achieving science literacy is a monumental task. Still, a general view of science education might include learning science, learning about science, and learning how to do science (Hodson, 1993). Historically, science education emphasized learning science; that is the facts, theories, and laws of science. Learning *about* science and how to *do* science has received much less attention. As mentioned previously, contemporary science education reform promotes the learning of science as inquiry. "Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on the evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world" (NRC, 1995, p.23). This movement towards inquiry, not a new one but, never before realized, views understandings about and abilities to do inquiry of equal importance to knowledge of science laws, theories, and facts.

As stated above, models and modeling play a critical role in the scientific endeavor. Students can reap similar benefits to scientists by participating in similar activities. Modeling also provides a means for students to learn science, about science, and how to do science (Gilbert and Boulter, 2000). "Models are integral to thinking and working scientifically because models are science's products, methods, and its major learning and teaching tools (John K. Gilbert, 1993, pp. 9-10). Constructing simulation models can provide opportunities for students to learn important science concepts, such as diurnal cycling and predator-prey relationships. It also provides an opportunity for students to learn how scientists use model-based reasoning and computational technologies in order to investigate complex phenomena. Finally, students can learn how to use such technologies to make sense of the natural world themselves. A review of literature on modeling in school science reveals that modeling can be a powerful activity for school science students. Modeling provides opportunities for students to demonstrate important thinking strategies (Stratford, 1995), learn science subject matter (Harrison & Treagust, 2000; Schwarz & White, 1998; Wells, Hestenes, & Swackhammer, 1995), and learn about science (Schwarz & White, 1998; Wisnudel-Spitulnik, Kracjik, & Soloway, 1999).

### 1.1.3 Teaching for Understanding Requires Specialized Knowledge

To teach anyone about any topic, one must possess in-depth knowledge about that subject. Subject matter knowledge alone is not enough. Contemporary reform in science education requires even greater emphasis on aspects of teachers' subject matter knowledge in order to teach in a "… manner consistent with the nature of scientific inquiry (American Association for the Advancement of Science, 1989, p. 200)." If teachers are to engage students in reasoning about scientific phenomena, they must themselves have a grasp of the important ideas of science as well as a deft understanding for how scientific knowledge is developed and justified (Kennedy, 1998). Evidence suggests that many teachers do not possess knowledge of this kind (R. D. Anderson &

Mitchener, 1994; Lederman, 1992). A question arises: *How might teachers be best supported in learning how to use important tools and methods that scientists use in the development of new knowledge, such as models and modeling, to engage their students in learning core science knowledge, about science, and how to do science?*

**1.1.4 Teacher Knowledge About Scientific Models and Modeling**

The professional development standards for teachers of science in the National Science Education Standards recommend that science teachers should learn content themselves through the perspectives and methods of inquiry (National Research Council, 1996). The implication of this recommendation is that if science teachers learn science as inquiry they will be better prepared to engage their own students in learning science as inquiry. There is little evidence to suggest that science teachers are being or have been taught in this way. To the contrary it has been suggested that traditional science teacher preparation in science consists of the mastery of fact-dominated information and conveys an image of scientific inquiry that is not consistent with actual scientific practice (R. D. Anderson & Mitchener, 1994). It is unreasonable to expect prospective science teachers to engage their students in scientific inquiry, if they themselves have limited understandings and experiences with important aspects of the scientific endeavor such as modeling. If students are to become scientifically literate, in part through understanding the nature of science, it stands to reason that their teachers must understand how science works, so that they can model appropriate behaviors and attitudes (Abell & Smith, 1994, p. 475). Empirical research suggests that both inservice and prospective science teachers possess uninformed and/or alternative views, in particular, of the role of models and modeling in science (Crawford & Cullin, 2002; De Jong & van Driel, 2001; Harrison, 2001b; Justi & Gilbert, 2001; Smit & Finegold, 1995; van Driel & Verloop, 1999b).

**1.2 Overview of the Study**

In the spring of 2002, we implemented an instructional module on scientific modeling in a content course designed for prospective science teachers. The module was designed to enhance the prospective teachers' understandings of the role of models and modeling in science. Through their participation in building, testing, and thinking about scientific models, we hoped the prospective teachers would recognize the importance of modeling in science and begin to consider how models and modeling might fit into school science classrooms.

The module included numerous activities and its design made use of a Project-Based Science Framework (PBS). Marx, Blumenfeld, Krajcik, and Soloway (1997) identified five features of PBS: a driving question, investigations, artifacts, collaboration, and technological tools. In the module we designed, the driving question was based on considering the effects cutting down trees near a pond in a wooded setting might have on the fish population in the pond. The complex nature of pond ecosystems makes computer simulation modeling an appropriate method of scientific inquiry. The prospective teachers had the opportunity to build and test computer models using the dynamic computer modeling software Model-It (Jackson, Krajcik, & Soloway, 2000). The model building and testing tasks were coupled with field studies of two ponds. We augmented the Project-based Science approach with an explicit, reflective approach (Abd-El-Khalick

& Lederman, 2000). Such an approach involves the coupling of inquiry-based activities with opportunities for prospective teachers to reflect on their experiences from within an explicit framework. Therefore, in addition to the field study and modeling activities, the students participated in research and discussion about scientific modeling with an emphasis on the role of models and modeling in the scientific endeavor.

### 1.2.1 How This Study Fills A Need

This study addresses the issues raised above by targeting an area of science teacher knowledge, namely scientific modeling. Empirical research suggests that many teachers possess modeling understandings that are inadequate for supporting the development of students' understandings and abilities in that regard. While both in-service and prospective science teachers' understandings of scientific modeling have been investigated, their understandings have not been examined in the context of actively engaging in scientific modeling. The methods employed in other studies have been relegated to articulated understandings via questionnaires (van Driel & Verloop, 1999b) and interviews (Crawford & Cullin, 2002; De Jong & van Driel, 2001; Harrison, 2001b; Justi & Gilbert, 2001; Schwarz & White, 1998; Smit & Finegold, 1995). An underlying premise of this study is that a more robust description of teachers' understandings can be developed through the following means: (1) engaging them in scientific modeling; (2) examining the manner in which they construct models; (3) studying the actual models they build, and (4) examining their articulated understandings about models and modeling.

### 1.2.2 Research Questions

The research is guided by the following questions:

> Question #1: What are prospective science teachers' understandings of scientific models and modeling, and in what ways do they change during modeling tasks that include building and testing computer models of pond ecosystems?
>
> Question #2: What is the nature of the models prospective science teachers construct during the modeling tasks?
>
> Question #3 In what ways do prospective science teachers go about constructing models during the modeling tasks?

## 1.3 Overview of the Thesis

In the next chapter of this thesis I provide a review of the research relevant to this study. I situate the study in the broader context of science education, with an emphasis on identifying gaps in the literature this study addresses. The physical and social contexts in which an activity takes place are an integral part of the activity, and the activity is an integral part of the learning that takes place within it (Putnam & Borko, 2000). Due to the importance of the context of the modeling module, I provide a rationale for the instructional design of the module in Chapter 3. This will be followed by a detailed description of each class session. In Chapter 4 I describe the methods of inquiry that informed the design, data collection and analysis of this qualitative research. For this study, a case-study design has been selected. The specific methods of analysis varied, depending on the research question and data sources. In Chapter 5 I present the results of my analysis for each of my three research questions. In Chapter 6 I discuss those results in light of existing science education research. I also make assertions in Chapter 6, addressing each research question individually, as well as the interplay among the research questions. Finally, in Chapter 7, I discuss implications for science education research, science teacher education, and science teaching and learning.

# Chapter 2

## REVIEW OF THE LITERATURE

In this chapter I present a review of the literature relevant to the topic of prospective science teachers' understandings of the role of models and modeling in science. I begin by situating scientific models and modeling in the context of contemporary science education reform. Next I discuss science teachers' knowledge, critiquing the empirical studies that point to what knowledge is most essential for teaching in a manner consistent with contemporary reforms. Based on the literature I identified six dimensions that represent the most essential and commonly examined aspects of understandings of models and modeling. They are: form of models, purposes of models, building models, changing models, multiple models, and validating models. In light of those dimensions I next discuss studies of modeling understandings by dividing the studies into three general categories: 1) pre-college students' understandings, 2) inservice teachers' understandings, and 3) prospective teachers' understandings. My study centered on the examination of prospective science teachers' understandings of the role of models and modeling in science in the context of an innovative instructional module that included building and testing dynamic computer models. Therefore, studies that report on others' instructional efforts to enhance modeling understandings are particularly germane. I discuss these studies as well. Finally, I situate my study in the existing literature by reviewing the conclusions that have been reached and the questions that have been raised.

**2.1 Scientific Models and Modeling in the Context of Science Education Reform**

A common theme echoed in contemporary science education reform documents in the U.S. is that the scientific endeavor itself, not just its outcomes, is to be considered something to learn (e.g. American Association for the Advancement of Science, 1989, 1993; National Research Council, 1996). It is clear from research on teaching and learning that through their pedagogy, teachers represent the character of their disciplines (Kennedy, 1990). In other words, "… the method by which one teaches a subject itself conveys important information to students about the subject matter (Kennedy, 1998, p. 252)." It stands to reason then that in order to properly portray the scientific endeavor for their students, teachers must teach in a manner consistent with the scientific endeavor itself. Reform documents promote teaching and learning science as inquiry:

> Scientific inquiry refers to the diverse ways in which scientists study the natural world and propose explanations based on evidence derived from their work. Inquiry also refers to the activities of students in which they develop knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world (National Research Council, 1996, p. 23).

Teaching science as inquiry and raising the level of emphasis on the *how* of science verses the *what* of science (Duschl, 1994) is a more lofty goal than merely helping students develop scientific process skills such as observation, measurement, recording data, etc. The pedagogy for science teaching is one that actively engages students in reasoning about scientific phenomena (Kennedy, 1998, p. 251). In instances where a phenomenon is inaccessible for some reason, scientists often utilize model-based reasoning. In essence, the behavior of an unexplained phenomenon is investigated through the examination of a familiar, well-understood phenomenon called a model. For instance, the mechanism inside a wristwatch could be investigated without taking the wristwatch apart by building a model wristwatch that behaves like the real wristwatch. If the model behaves like its target, the modeler has developed one explanation of the behavior of the target. If the model does not behave like the target, the model likely needs to be revised.

Models are and have always been essential to the scientific endeavor. It has even been suggested that science be defined as the process of constructing predictive conceptual models (S. Gilbert, 1991). An education in science should accomplish more than instructing students with respect to the conclusions of science; it should also encourage them to develop insights about science as an intellectual activity (Stewart, Hafner, Johnson, & Finkel, 1992). Engaging in modeling provides authentic context for accomplishing both.

### 2.2 Science Teacher Knowledge

Teachers must develop teaching strategies using a certain knowledge base, if the goals of contemporary science education reform are to be realized. Numerous writers and researchers have described domains of teacher knowledge that they believed to be the necessary components of a knowledge base for teaching. Borko and Putnam (1995) presented a conceptual framework for the knowledge base of teachers based on categories of teacher knowledge proposed by Shulman and colleagues (Grossman, 1990; Grossman, Wilson, & Shulman, 1989; Shulman, 1986, 1987). The framework was organized around three domains of knowledge particularly relevant to teachers' instructional practices: general pedagogical knowledge, subject-matter knowledge, and pedagogical content knowledge. Different domains interact and promote changes and development of teachers' knowledge no matter how they are delineated. Ultimately, it is teachers' subject matter knowledge that is transformed and used to achieve instructional objectives. Subject matter knowledge in science has been thought to be comprised of content knowledge and knowledge of what Schwab (1978) referred to as the substantive and syntactical structures of the discipline (Grossman, 1990). Knowledge of content includes knowledge of the laws, theories, facts, and major achievements of a discipline. Substantive structures of the discipline are the various paradigms within a field that affect both how the field is organized and questions that guide further inquiry (Grossman, 1990; Schwab, 1978). The syntactic structures of a discipline include the ways of establishing new knowledge; an understanding of the canons of evidence and proof within a discipline, or how knowledge claims are evaluated by members of the discipline (Grossman, 1990; Schwab, 1978). Ball combined content knowledge and knowledge of the substantive structures of the discipline and referred to knowledge of subject matter (Ball, 1990). Similarly she referred to what was previously defined as syntactic structures of the discipline as, knowledge about a discipline (Ball, 1990).

Regardless of the terminology used, it would seem that, in light of contemporary science education reform, a vital component of teachers' subject matter knowledge is a sense of the manner in which new knowledge is developed in a given field of study.

Modeling is one means by which new knowledge is generated in many fields of science. Therefore, teachers need to understand model-based reasoning and how models are used in generating explanations about natural phenomena.

## 2.3 Dimensions of Modeling Understandings

What are essential modeling understandings for teachers to possess in order to support students in doing modeling and learning about models and modeling in science? One approach to answering this question is to identify and examine studies of teachers and students' modeling understandings. A small number of studies of this nature exist in the literature. Table 2.1 displays aspects of scientific models and modeling that have served as a means for describing teachers' and students' understandings in the studies.

**Table 2.1**

*Categories of Modeling Understandings*

| Study | Categories of Models and Modeling | Subjects |
|---|---|---|
| Grosslight, Unger, Jay, and Smith (1991) | • Kinds of models<br>• Purpose of Models<br>• Designing/creating models<br>• Changing Models<br>• Multiple Models for the Same Thing | 7th grade general science students, 11th grade honors students, experts with interest in models |
| Smit and Finegold (1995) | • Function of models<br>• Nature of models | Prospective physical science teachers |
| Schwarz and White (1998) | • Kinds of models and model attributes<br>• Model content<br>• Multiple models<br>• Constructed nature of models<br>• Modeling process<br>• Designing and creating models<br>• Changing models<br>• Model evaluation | Middle school students |
| van Driel and Verloop (1999) | • Types of representation<br>• Goals and functions<br>• Characteristics | Inservice science teachers |

| | | |
|---|---|---|
| | • Design and development | |
| Justi and Gilbert (2003) | • Nature of models<br>• Use of models<br>• Entities of models<br>• Uniqueness of models<br>• Time span of models<br>• Status for making predictions<br>• Accreditation of models | In-service teachers: fundamental level (for students age 6-14), medium level (for students age 15-17), medium level pre-service student teachers, university chemistry teachers |

Many of the categories identified in the empirical studies above are common to each. For example, kinds of models (Grosslight, Unger, Jay, & Smith, 1991), nature of models (Smit & Finegold, 1995), model attributes (Schwarz & White, 1998), types of representation (van Driel & Verloop, 1999a), nature and entities of models (Justi & Gilbert, 2003) all refer to the *form* a model takes. Another dimension, included in nearly every study but called by different names, is the *purpose* of models. Many of the studies emphasized the process of *building* models under various names including designing models, creating models, construction of models, and development of models. Also receiving attention in many of the studies was the category of changing models. Only Justi and Gilbert (2003) appeared to have called the category of changing models by another name, referring to it as the time span of models. Two other important dimensions that appeared in a relatively few number of the studies are *multiple models* and *validating* models. The former was called the uniqueness of a model (Justi & Gilbert, 2003). The same authors referred to the latter feature as accreditation. Schwarz and White referred to it as model evaluation (1998). The other studies did not examine model validation. This is an interesting oversight in many of the studies, since the manner in which models are validated is a critical aspect of modeling.

Based on those aspects of models and modeling that have been most frequently examined and those considered most critical from a scientific perspective, there appear to be six *dimensions of scientific model and modeling understanding.* The six dimensions are: form of models, purpose of models, building models, changing models, multiple models, and validating models. In the next section I discuss studies examining pre-college students, inservice and preservice teachers' understandings in light of the six dimensions.

## 2.4 Students', Inservice Teachers', and Preservice Teachers' Modeling Understandings

Research related to modeling understandings can be separated into three groups: 1) pre-college students, 2) in-service teachers; and 3) prospective teachers. Each of these areas of empirical research will be discussed in turn.

### 2.4.1 Pre-college Students' Understandings

Grosslight, Unger, Jay, and Smith's (1991) study in the domain of understandings about models and modeling in science is considered seminal in this area. The authors interviewed middle ($7^{th}$ grade) and high school ($11^{th}$ grade honors biology) students and experts (adults with specialized knowledge or interest in models) about their conceptions of models and model use in science. The interview questions were organized into five themes: kinds of models, purpose of models, designing and creating models, multiple models for the same thing, and changing models. The researchers found that three general levels of models and modeling understanding emerged from the analysis of interviews.

The authors suggested that the levels of modeling understandings were closely tied to the person's epistemological views of science. The typical 7th grader exhibited a Level I model conception typified by a simple copy theory epistemology. They believed that the purpose of a model is to replicate the real thing. They did not distinguish between the ideas and/or purposes underlying the model, the model itself, and the experimental data that would support or refute the validity or usefulness of a model.

Most of the 11th-grade honors students possessed Level II conceptions about models. They distinguished between ideas and/or purposes motivating the model and the model itself, and realized that the purpose of the model dictates some aspect of the form of the model. They also recognized how experimental evidence might show that some aspects of a model may be wrong and need to be changed, and they imagined in a limited way that a model might have to be revised. The authors provided three features of Level II conceptions that suggest that the viewpoints held by those students falling into that classification are still not sophisticated "constructivist" conceptions (i.e., models used in the development of a deeper understanding of natural phenomenon). First, those students still viewed models as representations of real-world objects or events and not as representations of ideas about real-world objects or events. Second, different models were thought to capture different spatio-temporal views of the object rather than different theoretical views (i.e., the model might help one see something more clearly but not represent an alternative explanation). And third, students viewed models primarily as a means to communicate information about real-world events rather than as a means to test and develop their ideas or theories about the world.

Level III status was reserved for the experts who generalized about the types of models. Two basic categories emerged: physical models that can be physically handled and abstract models including mathematical equations and mental images. The experts' conceptions of the role and/or purpose of models in science can be summarized as follows:

1) Models exist as aids to understanding phenomena and this understanding can be checked or verified by comparing the results obtained by manipulating the model to observations obtained in the real world;
2) A primary guideline for making a model is to consider its purpose which is mediated by the extent of one's interest in structure, function, explanation, precision, predictive power, communication, and/or scope;
3) A scientist can have more than one model for the same thing because different models can be used to address different specific interests or questions about the referent; and
4) Scientific models can change (replaced by one that is a better tool for answering questions or by one that incorporates newer, more appropriate mathematics).

**2.4.2 In-service Teachers' Modeling Understandings**

The study by Grosslight et al. (1991) has served to lay the groundwork for much of the work related to modeling understandings that has since been undertaken. Van Driel and Verloop (1999a) reported findings associated with a Dutch curriculum innovation project directed at shifting the focus in science teaching from the content of scientific models to the nature of scientific models. The researchers explored experienced science teachers' knowledge about scientific models and modeling by means of open-ended and Likert-type questionnaires. Both questionnaires were based on the themes developed by Grosslight et al. (listed above) and condensed to 1) types of representations of models, 2) goals and functions of models in science, 3) characteristics of scientific models, and

4) the design and revision of models. The open-ended questionnaire utilized seven items, one for theme one and two items for each of the three other themes. The Likert-type questionnaire required the respondents to indicate to what extent certain statements were valid for models and modeling in science.

The results of this study suggest that the in-service teachers possessed limited views of the role of models and modeling in science. The criteria used by the science teachers for deciding what qualifies as a model varied considerably. They clearly articulated that models were used for explanatory and descriptive purposes. Yet, they rarely mentioned many important functions and characteristics of models. For example, teachers failed to acknowledge how models are used in making predictions or how models are used as a tool for obtaining information about a target that is inaccessible for direct observation. In addition, the teachers presented inconsistent views. For example, believing that a model must be as close to reality as possible while simultaneously suggesting that the purpose mediates the design of a model. A limitation of the methods employed by van Driel and Verloop, open-ended and Likert-style questionnaires, was that there were no provisions for investigating the reported inconsistencies in the teachers' views in more depth. The researchers only had access to what was written.

Van Driel and Verloop examined other factors associated with inservice teachers' knowledge of models and modeling in science such as teaching experience and subject area expertise. The authors indicated that there did not appear to be any correlation between teachers' experience and their modeling understandings (1999a). There was however at least one significant difference for teachers of different subject areas reported.

In contrast to the physics teachers in the study, chemistry teachers appeared committed to a positivist orientation of models punctuated by the suggestion that models must always be as close to reality as possible. Van Driel and Verloop contrasted a positivist orientation with a constructivist orientation, a view that would recognize that different models can coexist for the same target depending on the researchers' interest or theoretical point of view (1999a). Biology teachers were reported to hold views in between those held by the chemistry and physics teachers.

Harrison (2001a) examined how experienced science teachers use models to explain science to their students, and how models are treated by the textbooks used by teachers. In methodological contrast to van Driel and Verloop (1999a), Harrison utilized extensive interviews, consisting of first asking teachers how they approached teaching difficult subjects that lead to discussions of models and modeling. The teachers were then asked to comment on a series of analogical models. They were finally asked to respond to four assertions made by Gilbert (1993) that models are the main products of science, modeling is part of the scientific method, models are major learning and teaching tools in science education. Another difference in the two studies was the different emphases of the studies reported by van Driel and Verloop and Harrison. The latter investigated the teachers' pedagogical content knowledge related to scientific models and modeling or how they viewed and used models in their teaching. Van Driel and Verloop however investigated teachers' knowledge of the role of models and modeling in science.

Harrison compared teachers' responses to the classification system developed by Grosslight et al. and chose in some cases to rate teachers' as level 2/3 or 1/2 modelers.

Harrison explained that all of the teachers' responses collectively yielded a rich, comprehensive, and creative view of models that was well aligned with recommendations in the literature. Viewed individually though, only half of the teachers' demonstrated expert-like (level 3 or 2/3) modeling understandings. Others demonstrated modeling understandings that Harrison considered as "a problematic foundation for teaching secondary science (2001a, p. 417)." The teachers had a range of views related to changing models from "you cannot change accepted models" to models should be changed because "this is the essence of learning science" (Harrison, 2001a, p. 409).

Another finding reported by Harrison was the difference in the models offered as examples by teachers of various disciplines and the relationship between the textbooks used by the teachers and how those textbooks treated models. The teachers shared favorite explanations, analogies, metaphors or models used in their teaching during the interviews. Chemistry teachers offered the fewest number of models even though numerous models were found in their textbooks. When pressed, the chemistry teachers revealed that they did indeed use models from the text in a very purposeful manner. They did not however consider many of them models. Biology teachers offered more models than chemistry teachers, including concrete or scale models and process models such as feeding relationships and diffusion. Interestingly, some of the teachers did not regard simulations of natural selection as mathematical models and none of the teachers accepted evolution as a theoretical model. Physics teachers were reported to have volunteered the most models and appeared to be the most creative in their use. Van Driel and Verloop (1999a) presented similar findings in their study (previously discussed) when they reported that physics teachers held more constructivist views of models than did teachers of biology or chemistry. Harrison reported that few of the textbooks identify models as models. Also, few of the textbooks discuss the role and limitations of models. This is especially important in light of the fact that many new and inexperienced teachers rely on textbooks as an important resource in the development of their own subject-matter knowledge as well as in the development of curriculum.

In three publications, Justi and Gilbert (2001; 2002; 2003) reported on a study into the epistemological status of models attributed by teachers in Brazil and the U.K. They examined experienced teachers' views on the nature of models, the nature of modeling, the implications of those views for the education of modelers, and their use of models and modeling in the context of science education. The researchers used a semi-structured interview method. The group of 39 teachers interviewed included teachers with degrees in elementary education who teach 6-14 year olds, biology, and chemistry; teachers with degrees in chemistry, physics, or biology who teach 5-17 year olds, undergraduate pre-service education instructors, and university teachers of chemistry. A strength of this study was the use of in-depth interviewing which permitted the researchers to identify nuances in teachers' understandings.

Justi and Gilbert identified seven aspects of the notion of model from the interview data: the nature of a model, the use to which it can be put, entities of which it consists, its relative uniqueness, the time span over which it is used, its status in respect of the making of predictions, and the basis of accreditation for its existence and use. They also found what they termed categories of meaning for each aspect, or differing views related to the identified aspects. Justi and Gilbert concluded that in general, teachers do not possess the kind of comprehensive knowledge and skills consistent with being able to use models to support students in learning science, learning about science, and learning how to do science. The researchers criticized the notion of levels of modeling understanding suggested by Grosslight et al. They could not find patterns in their data that corresponded to Grosslight et al.'s levels. They did however report interesting results related to teachers' knowledge of various aspects of models and modeling.

Most of the teachers expressed more than one view for the nature of models. They often cited visualization, creativity, and explanation as purposes of models. When asked specifically about models being used to make predictions, most of the teachers acknowledged prediction as a purpose of models. Some also saw models as standards to be followed. Most of the teachers also recognized that multiple models could exist for the same phenomenon. Regarding changing models, most of the teachers acknowledged that models are changed when problems arise with its use or if its explanatory ability is inadequate. An alarming number of teachers (21%) suggested that models could not be changed. Few of the teachers mentioned the accreditation of models and those who did suggested that models are accredited by those have built the model.

Justi and Gilbert found some patterns related to the teachers' backgrounds and their views. First, those with primary teaching certificates held the simplest views of the nature of models. Biology teachers were reported to have views only slightly more sophisticated. Physics and chemistry teachers were found to be able discuss the notion of model in the most comprehensive way of all of the teachers that were interviewed.

### 2.4.3 Prospective Science Teachers' Understanding

There are even fewer studies reported in the literature about prospective science teachers' understanding of the role of models and modeling in science. Smit and Finegold (1995) studied the perceptions of models in general and models specific to optical phenomena of future physical science teachers. By means of a questionnaire, the researchers determined that the participants' level of knowledge of models was rather low. The prospective science teachers considered the function of a model as one of promoting a better understanding of reality as relatively unimportant. Instead, they viewed the principal function of models as that of helping one understand, to explain complex and abstract things and to demonstrate how things work. This represents a limited view of scientific models as merely a representation used by someone who understands the phenomenon to explain it to someone who does not.

De Jong and van Driel (2001) investigated the development of prospective science teachers' content knowledge and pedagogical content knowledge in the domain of models and modeling in the context of a post-graduate teacher education programs at the Institutes of Education of Utrecht University and Leiden University. The prospective science teachers in this study all held Master of Science degrees in chemistry. It is somewhat surprising then that the findings indicated their knowledge was not very pronounced and that some of the important functions of models; such as making and testing predictions were rarely mentioned by them.

**2.5 Attempts to Enhance Understandings About Scientific Models and Modeling**

There are a limited number of studies that report as a main objective, enhancing knowledge about scientific models. Of all of the studies reviewed thus far, De Jong and van Driel (2001) represented the only one in which a stated goal was to measure and/or describe change resulting from some form of intervention. The study was set in the context of an instructional module on teaching models and modeling. In the module the prospective science teachers considered questions about models and modeling, read and discussed research from science education journals on the topic, considered intentions for teaching about scientific models, examined model-dominant chemistry curriculum, and finally reflected on their own on-going pre-service teaching experiences. The apparent lack of improvement in the prospective science teachers' knowledge about models in science indicates the need for alternative experiences in order to confront prior understandings. I will now review two studies involving pre-college students.

In one study, Wisnudel-Spitulnik, Krajcik, and Soloway (1999) reported on the development of pre-college students' science understandings resulting from building and testing models of global climate change using the dynamic computer modeling software Model-It. The study is one of many that have centered on pre-college students' using Model-It. Stratford for instance, examined pre-college students' general and cognitive modeling strategies by examining process-video data captured while they built models. His research also included the examination of more than 50 student-built models (Stratford, 1996). In another study, Zhang, Wu, Fretz, Krajcik, Marx, and Davis compared the modeling practices of pre-college students and experts via process-video data captured while they were using Model-It (2002).

The study reported by Wisnudel-Spitulnik, Krajcik, and Soloway explored the understandings of one group of three students, who were considered representative of all of the 9th grade students involved in the study, engaged in a unit on global climate change (1999). The researchers examined inquiry and nature of science understandings as well as domain-specific understandings. They reported that through the direct experience of building a model, the students constructed moderate inquiry understandings and built a high level of nature of science understandings. It is worthy of mention that this achievement seems to have been accomplished without any explicit instruction on the role of models and modeling in science. Generally speaking, enhancing understandings of the nature of science is best accomplished through an explicit, reflective approach (Abd-El-Khalick & Lederman, 2000). The results reported by Wisnudel-Spiulnik et al., may need to be questioned based on how the level of understanding was gauged. The characterization of the students constructing "moderate" inquiry understanding was based on whether or not the students defined a problem, constructed a model, and constructed and evaluated an argument. Since the students in this case did not explicitly state the use of experimental evidence as a basis for evaluating their model and argument, their inquiry understandings were characterized as "moderate." Evaluating their ability to "do inquiry" was different than what they knew and understood "about inquiry." It seems that explicit attention to students' ability to articulate what they did and why they did it was needed. If the interview protocol used in this study included such explicit questioning, it was not made apparent.

Regarding the high level of nature of science understandings, it is quite evident that the students possessed quite sophisticated understandings of the purposes of models. They were able to clearly articulate the limits and assumptions of their models as well as describing the purpose of models as providing a means for testing ideas, making predictions, and educating a larger community. Again, there is no mention of any explicit instruction on the role of models and modeling in science associated with this study yet the students demonstrated expert-like understanding using Grosslight et al. (1991) for instance as a referent. This study is especially interesting in light of the fact that the participants were of an age exactly between the 7$^{th}$ and 11$^{th}$ grade students reported in Grosslight et al. The modeling experience seemed to really make a difference in these students' understanding of the role of models and modeling in science. The reported results must be accepted with caution though as only the students' experiences and commentary while building and testing the models was reported. There is no information provided about the students' understanding about the nature of science and modeling prior to this experience.

Another study, reported by Schwarz and White (1998) built on research centering on the ThinkerTools curriculum (White, 1993). The developers of ThinkerTools sought to create a computer-enhanced, middle school, science curriculum that would enable students to learn about the processes of scientific inquiry and modeling as they construct theories of force and motion. In the study reported by Schwarz and White, a "model-enhanced" version of the ThinkerTools curriculum was developed to teach students about the nature of models and the processes of modeling. The goal of teaching students about the nature of models and modeling, as well as the utility of modeling, was addressed by allowing students to choose and envision their own models based on data from their experiments. In some cases students chose from previously programmed models that were close to their intuitions (most likely based on common misconceptions, but no explicit mention is made), thus avoiding the need to provide instruction in programming. Other software features were also designed to foster student learning in this domain such as the computer "talking" about its behavior and the modeling rules being applied as a given simulation was run and the option to run simulations according to Newton's Laws.

The curriculum and instruction lasted 10.5 weeks and included explicit instructional activities, such as reading, reflecting, and discussing passages about models and modeling (e.g., what a scientific model is, how the ThinkerTools program works, and the utility of computer models). In addition, the students watched a videotape on the modern uses of computer simulation models, and then participated in a discussion about the various simulations highlighted in the videotape and their utility in society. The final stage of the experience involved students evaluating their models for accuracy, plausibility, mechanism, utility, and consistency. This was done to mirror practice in the scientific community where multiple, and often competing, models are often presented and evaluated; where some models are often better than others based on the criteria being used. During the model evaluation process, students had the opportunity to compare and contrast other students' models in class debates.

The researchers studied several themes of student understanding similar to those examined by Grosslight et al. (1991) but in considerably more depth and in the context of a specific curriculum. The themes included model content and attributes, the nature of the modeling process the evaluation of models, and the purpose of models and modeling. Students' understandings of the themes were examined by means of written assessments before and after the curriculum was experienced, student project reports, and student interviews. The primary assessment tool was a modeling questionnaire comprised of various formats including a sorting task, multiple choice questions, and enhanced true/false questions. Findings were triangulated by means of post-interviews and analysis of students' final research projects.

The researchers reported a significantly increased understanding of the nature of models. Over half of the 7$^{th}$ grade students were able to identify a scientific theory, a causal rule, and an equation as forms of models as compared to less than one-fourth prior at the beginning of the curriculum. The students also demonstrated moderately increased understanding of the nature of modeling. Some mixed results were reported regarding understanding the evaluation of models (e.g., many students thinking one model is as good as another). The researchers reported striking gains in their understanding of the utility of models with over half of the students recognizing a model as a predictive or explanatory rule. The students also appeared to recognize computer models, like the ThinkerTools software, were useful for visualizing and testing alternative models.
The results of the study reported by Schwarz and White (1998) suggest impressive gains in model and modeling understandings. The authors, in dutifully identifying potential

limitations of their findings suggest that their findings might have been more valid had they attempted to access the students' non-articulated understandings in addition to their articulated understandings.

## 2.6 Personal Experiences

I have collaborated in two pilot studies (Crawford & Cullin, 2002; Cullin & Crawford, 2002) in which an instructional module was designed to enhance prospective science teachers' understandings of the role of models and modeling in science. In consecutive semesters during the 2000-2001 academic year, we engaged prospective secondary science teachers enrolled in a methods course and teaching practicum, in modeling experiences highlighted by building and testing dynamic computer models. The studies used the public domain dynamic modeling software, Model-It. Through analyses of questionnaires, interviews, reflective writing, and designed lessons we examined prospective science teachers' understandings about and intentions of teaching about scientific models and modeling. As we expected based on reviews of the literature on teacher subject matter knowledge, most of them acknowledged that building and using scientific models was a new experience. Prior to the modeling experience, the prospective science teachers had limited views of the manner in which scientists use models. Much like the experienced and prospective teachers involved in the studies described above, our prospective teachers viewed models correctly as tools to enhance explanations. They failed however to acknowledge the important use of models and modeling in testing ideas and making predictions. There is evidence to suggest that for the second of the two groups, for whom we have pre/post data, after the modeling experience, the prospective teachers developed more articulate and robust ways to talk about the use of scientific models. Unfortunately their views about how scientists use models did not change significantly. There was a demonstrated shift in their views of how teachers can utilize models, from a single use of explaining concepts to using models as a cognitive tool to support students in constructing explanations about natural phenomenon.

While encouraged by these results, it has become obvious that an improved instructional sequence and set of experiences would be needed to meet the objective of enhancing the prospective science teachers' understanding of the manner in which scientists use models and modeling. If this objective can be achieved, the task of supporting prospective teachers in developing the ability to support their own future students in learning about and building scientific models will likely be facilitated. What we were able to accomplish in the two pilot studies was limited due to time, technological difficulties stemming from the software still being in development, and my own inexperience in teaching prospective teachers about the role of models and modeling in science. The science teaching methods course that provided the context for this instruction was already under time constraints due to a crowded syllabus. Time was just not available to provide an appropriate scientific context for model building. There is also some evidence to support the contention that the context of a science teaching methods course further confounded our efforts. This situation is likely due to the fact that the prospective science teachers' attention is focused on *learning how to teach* verses *learning about science* at this point in their preservice studies. There were also methodological and technical difficulties in data collection associated with both pilot studies.

**2.7 Summary**

Reforms, as found in contemporary science education literature, include placing greater emphasis on understandings and abilities of scientific inquiry including the role of models and modeling in science (AAAS, 1989; AAAS, 1993; NRC, 1996; NRC, 2001). Any description of what a teacher needs to know inevitably includes a reference to content or subject matter knowledge. To achieve the goals of contemporary science education reforms, and support the three reasons for science education espoused by Hodson (1993), science teachers' content knowledge must also include knowledge of the nature of science and scientific inquiry. They must understand the ways new knowledge is brought into the field; what Schwab (1978) referred to as syntactic structures of the discipline. If prospective science teachers have experiences engaging in authentic scientific inquiry, they are more likely to include this aspect of the syntactic structures of science in their own teaching (Windshitl, 2000). Unfortunately there is little evidence in the literature to suggest that teachers, prospective or practicing, possess either adequate knowledge of or experience with scientific models and modeling.

Teachers appear to understand that models can come in many *forms* but hold limited views of the *purpose* of models viewing models almost exclusively as instructional aids. Few teachers recognize important uses of models such as in making predictions and testing ideas. Little is reported in the literature about teachers' views on *building* models and while most acknowledge that models can be *changed,* few can provide an adequate rationale for doing so. There appears to be a strong connection between teachers' views of *multiple models* and purposes of models suggesting that their views of the former are similarly limited. There is perhaps less reported in the literature on teachers' views of *validating models* than any other dimension. What has been reported is that teachers do not view agreement between the behavior of a model and its target as a means for validating a model favoring.

Practicing teachers' understandings of the role of models and modeling in science have been examined more extensively than have prospective teachers' understandings. Therefore little is known about prospective teachers' understandings. Also, the only studies, in addition to those with which I have been associated, in which prospective teachers were the subjects under study have involved teacher preparation programs very different to those commonly found in the United States. The study reported by De Jong and van Driel (2001) for instance involved prospective chemistry teachers, all of whom held Master of Science degrees in Chemistry. Such programs are not typical in the United States.

The assessment of teachers' modeling understandings appears to be problematic. Grosslight et al. (1991)paved the way for subsequent researchers by developing a 3-level classification system for modeling understandings. Some researchers have criticized this 3-level classification system as too broad. Justi and Gilbert (in press) concluded that teachers do not display the kinds of stages or levels identified by Grosslight et al. Instead, they suggested that teachers show understandings made up of positions within a series of distinguishable but inter-related aspects of models and modeling. students in building models of natural phenomena and learning how scientists use them to do the same. It also appears that what researchers mean by "model" is unclear. Justi and Gilbert (2001; 2002; in press) and Harrison (2001a) appeared to be most interested in models used in teaching. Van Driel and Verloop  and Smit and Finegold (1995) appeared to focus on models used by scientists. However, both reported teachers' conceptions in both domains without making the distinction. Teachers need to possess extensive knowledge of how scientists use models *and* how to use models in instruction.

It has been shown that engaging students in modeling activities can contribute to their understanding of the role of models and modeling in science. The two studies I examined involved extensive, time-intensive curricula designed specifically to enhance modeling understandings in conjunction with the development of domain-specific knowledge of what was being modeled. Effective practices can be identified through a comparison of the ThinkerTools (Schwarz and White, 1998) and Global Climate Modeling (Wisnudel-Spitulnik et al., 1999) contexts. Both studies made extensive use of computer modeling. Each used different subject matter however as the context for learning about modeling in science. The study by Schwarz and White (1998) used a well-understood, non-controversial topic: forces and motion. Students did not construct models but chose from among models that were consistent with their own mental models. The Wisnudel-Spitulnik et al. (1999) study focused on global climate change and the students did build their own models. The phenomenon being modeled was much more complex and controversial. Global climate change <u>can only be</u> studied via modeling, due to the dynamic, complex and systemic nature of the phenomenon. Forces and motion, by contemporary standards while important, could be studied in other ways. Modeling, as it was undertaken in the Global Climate Modeling curriculum, might be considered more authentic modeling, due to the nature of the phenomenon and the modeling experiences it provided. It is difficult, however, to discount the impressive gains in modeling understandings reported by Schwarz and White (1998), even if the context of the modeling was not as authentic.

Perhaps the most important unifying feature of both studies was the emphasis on engaging students in scientific modeling activities. While there are no reported studies in which students (or teachers for that matter) are merely informed, via direct instruction for instance, as to the importance and utility of models and modeling in science as an intervention, it seems logical that any attempts to enhance such views should include authentic scientific modeling experiences. Research has shown that expecting students or teachers to learn targeted aspects of the nature of science and scientific inquiry merely through participation in inquiry experiences is ineffective (Abd-El-Khalick & Lederman, 2000; Lederman, 1992; Schwartz, Lederman, & Crawford, 2000). Instead, an explicit-reflective approach is recommended in which "the use of science-based activities should be coupled with opportunities to help learners, prospective teachers specifically, reflect on their experiences from within an explicit framework that outlines certain aspects of nature of science (Abd-El-Khalick & Lederman, 2000, 694-695)."

Finally, various methods of inquiry were employed. However, most of the researchers have focused on subjects' articulated understandings. Schwarz and White suggested this as a potential limitation of their study (Schwarz & White, 1998). In contrast, Stratford (1996) examined students' approaches to modeling and the models they built and Zhang et al., (2002) examined students' and experts' approaches to modeling only. Neither group of researchers examined students' modeling understandings, however. To date, there have been no studies examining both articulated as well as non-articulated understandings as they are revealed in the processes (the modeling) and products (models).

# Chapter 3

# CREATING A CONTEXT FOR LEARNING ABOUT SCIENTIFIC MODELING

## 3.1 Introduction

In this chapter I will first provide a rationale for the design of the module from a scholarly perspective. Next I will provide background on the course in which the module was implemented. Finally, the manner in which the module actually played out will be described in detail.

In the spring of 2002, we designed and implemented an instructional module on scientific modeling in a secondary science preservice content course. The modeling module was designed to enhance the prospective teachers' understandings of the role of models and modeling in science. Through their participation in building, testing, and thinking about scientific models, we hoped the prospective teachers would understand the importance of modeling in science and begin to consider how models and modeling might fit into school-science classrooms.

Critical to the success of the module was the context we created for the prospective teachers. The module utilized a Project-Based Science or PBS (Krajcik, Blumenfeld, Marx, & Soloway, 1994; Marx et al., 1997) approach highlighted by the use of the simulation modeling software Model-It to model pond ecosystems. Coupled with modeling tasks were field studies of two ponds and opportunities to reflect on and discuss the role of models and modeling in science.

### 3.2 Rationale and Theoretical Foundation for the Design of the Module

The design of the instructional module on scientific modeling was informed by science education literature related to reform-oriented views on science and science teacher education, teachers' knowledge about scientific models and modeling, constructivist approaches to teaching and learning, research on teachers' and students' understanding of the nature of science and scientific inquiry, and our own experiences teaching prospective teachers about inquiry and the nature of science. In this section I will describe each decision we made in designing the module and present a rationale for that decision. Table 3.1 provides an abridged version of the rationale.

**Table 3.1**
*Rational for the Design of the Modeling Module*

| Decision | Rationale |
|---|---|
| Focus on scientific modeling | • Designed to promote meaningful learning<br>• Science Education reform emphasizes inquiry<br>• Modeling is an important component of inquiry<br>• Teachers do not possess in-depth knowledge of modeling<br>• Teacher knowledge (all domains) is both the vehicle and object of change<br>• Easy-to-use modeling software exists |
| Set the module in SCIED 410 verses SCIED 412 | Our experience is that prospective teachers at this stage in their preparation are often more interested in learning about specific classroom practices than learning about NOS and scientific inquiry; more time available for this kind of study in SCIED 410… actually the whole purpose of the course |
| Why a PBS approach? | Teachers are learners and their learning is influenced by:<br>• existing knowledge and beliefs<br>• context<br>• social interaction |
| Why the explicit/reflective approach? | An explicit-reflective approach appears to be the most effective means for influencing conceptions of the nature of science and scientific inquiry |
| Why Model-It | • Provides a good example of simulation modeling; the modeling process is well represented by the software<br>• Software is easy to learn and use<br>• Software is designed well<br>• Software is free and downloadable (at the time of this study) |

### 3.2.1 Why focus on teachers' knowledge of the role of models and modeling in science

The designers of the module intended to emphasize inquiry and the nature of science. Much of contemporary reform in education focuses on the goals of what Brophy (1989, p. 349) calls "teaching for meaningful understanding and self-regulated learning." Such goals require "instructional approaches that enable students to take more active roles in their learning and to work independently and collaboratively to construct more powerful and flexible knowledge and understanding" (Borko & Putnam, 1995, p. 38). In science education, scientific inquiry is at the forefront of reform–oriented views. One aspect of scientific inquiry worthy of attention is modeling. For example, the National Science Education Standards recommend that throughout grades 9-12, students should formulate and revise scientific explanations and models using logic and evidence:

> Student inquiries should culminate in formulating an explanation or model. Models should be physical, conceptual, and mathematical. In the process of answering the questions, the students should engage in discussions and arguments that result in the revision of their explanations. These discussions should be based on scientific knowledge, the use of logic, and evidence from their investigation (NRC,1996, p. 175).

Modeling is an endeavor that provides opportunities for meaningful learning and cognitive activity. Stratford, for instance, identified numerous cognitive activities associated with modeling such as analyzing, relational reasoning, synthesizing, and testing and debugging (1995). Modeling provides opportunities for exploratory activities in which students use models to encounter ideas about a topic presented by someone else and expressive activities in which learners can develop and test their own ideas (Mellar &

Bliss, 1994). Due to its importance in science and many opportunities it presents for meaningful learning, we chose modeling as a specific aspect of scientific inquiry on which to focus the module.

Teaching for understanding is often difficult for teachers because it represents a departure from the manner in which most teachers have been taught. Most teachers have experienced what Anderson (1989) called a receptive-accrual approach to learning consisting of largely didactic methods of instruction. In this kind of approach, "the learner's role is to receive and practice information and skills presented by the teacher" (Borko & Putnam, 1995, p. 42). Change requires awareness that a didactic approach often does not support meaningful learning and self-regulation. It also requires teachers to develop knowledge they may not have. This is especially true for prospective teachers. Borko and Putnam suggest that teacher knowledge structures are both the objects and vehicles of change (1995). In the instructional module we designed, the primary goal was to enhance prospective teachers knowledge of the role of models and modeling in science.

One of the most important responsibilities of reform-oriented science teachers is to accurately portray the scientific endeavor to their students. The National Science Education Standards recommend that students develop understandings about and abilities to do scientific inquiry (NRC,1996). In Science for All Americans, it is stated that "Teaching should be consistent with the nature of scientific inquiry" (AAAS,1989, p. 201). The role of models and modeling in science represents an important and often neglected aspect of scientific inquiry (J. K. Gilbert, 1995). Placing scientific inquiry at the core of science education reform requires teachers to have in-depth knowledge of aspects of scientific inquiry and the nature of science.

Unfortunately, there is little evidence to suggest that science teachers, both pre-service and in-service, possess the kind of in-depth understandings about the role of models and modeling in science necessary to support students in learning about and how to do scientific modeling. Inservice and prospective science teachers often recognize the usefulness of models as pedagogical tools but they too often fail to attribute to models the function of idea testing. Van Driel and Verloop (1999b) for instance reported that inservice teachers used various criteria for deciding what qualifies as a model and rarely mentioned the important role played by models in making predictions and obtaining information about an inaccessible target. Harrison (2001b) reported that only 2 of 25 inservice teachers he interviewed expressed the belief that models could be used as thinking tools. In a study of inservice teachers' views of the nature of modeling, Justi and Gilbert reported that the sample of teachers they interviewed did not generally emphasize the need for a consideration of the scope and limitations of models during the process of modeling nor importance of the discussion of such matters during the presentation of any models to students (2002).

Few studies have focused on prospective science teachers' understandings about the role of models and modeling in science. Smit and Finegold (1995) examined the conceptions of the origin, nature, and functions of scientific models possessed by 196 final-year perspective physical science teachers. They concluded that the prospective teachers' knowledge of modeling was limited. The prospective teachers emphasized the utility of models as aids in explaining complex and abstract concepts and for use in demonstrating how things work rather than as a tool for promoting a better understanding of reality. A study reported by De Jong and van Driel (2001) is especially notable in that it described the development of prospective teachers modeling understanding resulting from explicitly emphasizing the role of models in science in a post-graduate teacher education course. All of the participants in the De Jong and van Driel (2001) study held masters of science degrees in chemistry. It is somewhat surprising that the authors reported that the prospective teachers' knowledge was not very pronounced. The prospective teachers participated in a module on scientific modeling in which they considered questions about models and modeling in science, read and discussed research from science education journals on the topic, considered their own intentions for teaching about scientific models, examined model-based chemistry curriculum, and reflected on their own on-going pre-service teaching experiences. It is surprising that the researchers reported little or no improvement in the prospective teachers' knowledge of models in science.

From a review of literature on teachers' knowledge regarding models and modeling we concluded that this was an area in need of attention. Given the focus on modeling we had to decide on an appropriate setting for the module.

**3.2.2 What course would provide the best opportunity for success**

In our previous work we endeavored to enhance prospective science teachers understanding of the role of models and modeling in science by engaging them in meaningful computer modeling activities coupled with field work and explicit instruction and reflection. In a recent study, we reported on our use of Model-It in an advanced science teaching methods course (Crawford & Cullin, 2002). We found that prospective science teachers initially held the view that models were tools used by someone who understands a phenomenon to facilitate an explanation of the phenomenon to someone who does not understand. This limited view neglects the critical role played by models and modeling in the development of scientific knowledge. In a relatively short period of time (9 hours total), we found that engaging prospective teachers in model building and testing with the simulation modeling software Model-It supported some desired shifts in their understandings about models and modeling in science. After participating in modeling activities, many of the prospective teachers we interviewed referred to models as tools used by a "user" to learn about something. This compared to their previous view of a model as essentially a pedagogical tool used by a more knowledgeable "other". However, there was little evidence to suggest that we made any great strides towards enhancing our prospective teachers' modeling conceptions related to how models are used in the development of new scientific knowledge.

In evaluating our initial foray into teaching prospective teachers about scientific modeling, we found it difficult to get them thinking about issues related to scientific inquiry and the nature of science in a methods course. The prospective teachers were more concerned about learning teaching strategies, class management, assessment, and lesson planning. It appeared to be the wrong time and place to engage them in modeling activities. We had experienced this in a previous study related to teaching about evolution and the nature of science (Crawford, Zembal-Saul, Munford, & Friedrichsen, accepted).

As a result of our experiences addressing issues related to inquiry and the nature of science, we chose to design a new module on modeling to be implemented in a "content" course for prospective science teachers. In part to meet this need we had recently developed a course (SCIED 410, *Technology Tools to Support Scientific Inquiry*) designed to help prospective science teachers develop a richer understanding of scientific inquiry and the nature of science while developing proficiency in using contemporary technologies (see Friedrichsen, Dana, & Zembal-Saul, 2001; Zembal-Saul, Munford, & Friedrichsen, 2002 for additional information about the rationale, theoretical underpinnings and development of the course).

SCIED 410 is the first in a three-course sequence for prospective science teachers at the Pennsylvania State University. We view it as a content rather than a methods course. Three central goals informed the design of the course: (1) engage prospective science teachers in authentic science experiences in a technology-rich environment designed to promote and support scientific inquiry; (2) situate science learning within a social context; and (3) promote reflection on learning

In its brief history, *Technology Tools to Support Scientific Inquiry* classes have been populated by both prospective secondary and elementary teachers in both science and non-science disciplines. Beginning with the 2001-02 academic year, the course became a required course for all secondary science education majors. Since that time, the course has been populated almost exclusively by secondary science majors with only a few prospective elementary majors enrolled. *Technology Tools to Support Scientific*

*Inquiry* is a 3-credit (3 semester hours per week) course that meets for approximately 90 minutes twice a week.

**3.2.3 What instructional approaches will be successful in meeting our goals**

The National Science Education Standards recommend that teachers of science "learn essential science content through the perspectives and methods of inquiry" (NRC,1996, p. 59). To do so science learning experiences for teachers should:

- Involve teachers in actively investigating phenomena that can be studied scientifically, interpreting results, and making sense of findings consistent with currently accepted scientific understanding.
- Address issues, events, problems, or topics significant in science and of interest to participants.
- Introduce teachers to scientific literature, media, and technological resources that expand their science knowledge and their ability to access further knowledge.
- Build on teacher's current science understanding, ability, and attitudes.
- Incorporate ongoing reflection on the process and outcomes of understanding science through inquiry.
- Encourage and support teachers in efforts to collaborate. (NRC,1996, p. 59)

The recommendations regarding appropriate ways to enhance teacher learning are consistent with contemporary views on learning. One factor, rooted in a constructivist philosophy, is that what students learn is dependent upon their existing knowledge and beliefs (Duit & Treagust, 1998; Tobin & Tippins, 1993). A second factor is that learning is situated. Knowledge is contextualized and cannot be easily separated from the situation in which it develops (Brown, Collins, & Duguid, 1989). Environment and culture represent a third factor believed to influence learning. Cognitive psychologists and recommend the establishment of communities of scientific practice based in the premise that "robust knowledge and understanding are socially constructed through talk, activity, and interaction around meaningful problems and tools" (Bransford, Brown, & Cocking, 2000, p. 184; Vygotsky, 1978).

In light of the recommendations of the standards and what we know about learning, we chose a Project-Based Science (PBS) approach. Marx, Blumenfeld, Krajcik, and Soloway (1997) identified five features of PBS: a driving question, investigations and artifacts, collaboration, and technological tools. A good driving question is worthwhile, encompasses real-world problems, and is feasible (Marx et al., 1997). The driving question must establish a context for well-conceived and authentic investigations. Also, inherent to PBS is the creation of artifacts that are the result of the processes involved in addressing the driving question. Building and testing computer models of a pond ecosystem in order to understand its behavior is simultaneously a process (investigation) and a product (an artifact). PBS is theoretically underpinned by the notion of situated cognition and social constructivism. Collaboration is a critical component of PBS since what students learn is influenced by social interaction (Marx et al., 1997). Finally, the technological component of the modeling module is ubiquitous. Utilizing technological tools enables authentic investigations and supports deep understanding and learning in ways that are not possible by other means (Marx et al., 1997).

Research on understandings related to inquiry and the nature of science suggest that students and teachers do not learn about important aspects of the scientific endeavor by merely participating in scientific activities. With this in mind, we augmented the Project-based Science approach with what Abd-Al-Khalick and Lederman refer to as an explicit, reflective approach (2000). Such an approach involves the coupling of inquiry-based activities with opportunities to help prospective teachers reflect on their experiences from within an explicit framework (Abd-El-Khalick & Lederman, 2000). We agree with Abd-Al-Khalick and Lederman that understanding of the nature of science and scientific inquiry are necessary but insufficient conditions for teachers to achieve the vision of contemporary science education reform (Abd-El-Khalick & Lederman, 2000). Engaging prospective teachers in learning science and learning about science via inquiry-based methods is a critical step toward developing the ability to teach in a manner consistent with the vision of the standards.

**3.2.4 Choosing a technological tool to support learning about scientific modeling**

The modeling module provided an opportunity to focus on both a technology and a topic related to the nature of science and scientific inquiry, namely modeling. Specifically, the kind of modeling emphasized was simulation modeling. In this kind of modeling, prevalent in much of the scientific modeling utilized today, underlying mechanisms and relationships are defined and the model is allowed to run over time to see what happens (Vanessa Colella & Klopfer, 2002). We chose the simulation modeling program Model-It, a learner-centered tool for building dynamic, qualitative-based models (Jackson et al., 2000). Model-It organizes the process of building a dynamic computer model into the tasks of planning, building, and testing (see Figure 3.1).

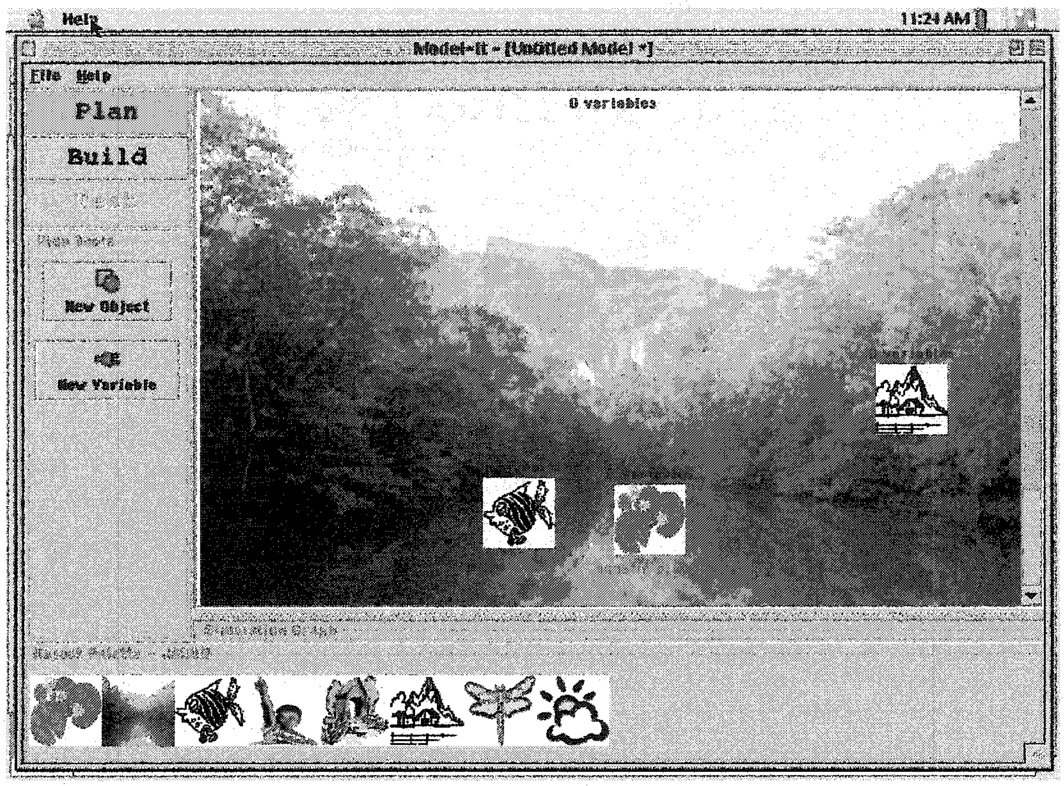



*Figure 3.1* **Graphic interface of Model-It in plan mode**

In building a model, users first identify objects to be included in the model. Objects are the actual physical constituents of the phenomenon under study. For example, in a pond ecosystem model (Figure 3.1) objects might include the water in the pond, fish in the pond, aquatic plants in the pond, and soil near the pond. Users can identify any number of objects to include in their model and represent them with digital images. It is possible to create a set of pre-determined high-level objects (shown in the lower left-hand corner of Figure 3.1) from which users can choose. Images obtained by other means such as scanned photographs or those downloaded form the World Wide Web, can also be utilized. Verbal prompts provide the user the option to describe the objects they define in terms appropriate for their setting (see Figure 3.2).

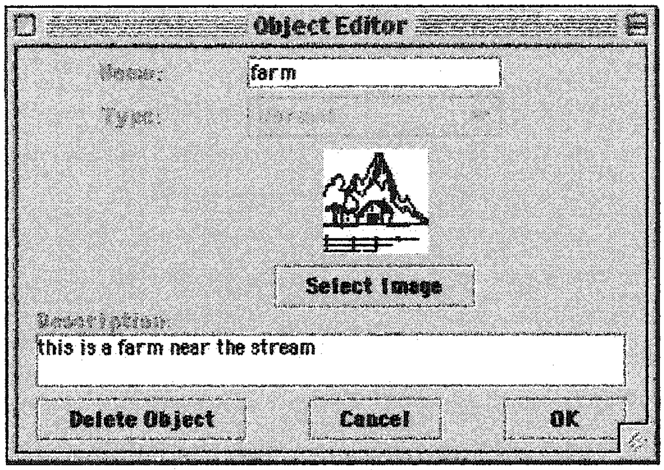



*Figure 3.2* **Object editor in Model-It**

After identifying the physical objects in the model, users then identify variables associated with each object (see Figure 3.3). These variables are physical quantities that describe certain attributes of objects. For example, once again referring to a pond ecosystem model, variables associated with the object "pond water" might include pH, turbidity, dissolved oxygen, and temperature. Variables associated with the object "fish" might include diversity, population, and size. When defining variables users have the option of choosing a qualitative (verbal) description, such as describing temperature as high, medium, or low (as in Figure 3.3) or a quantitative description, such as the Celsius temperature scale (as in Figure 3.4).

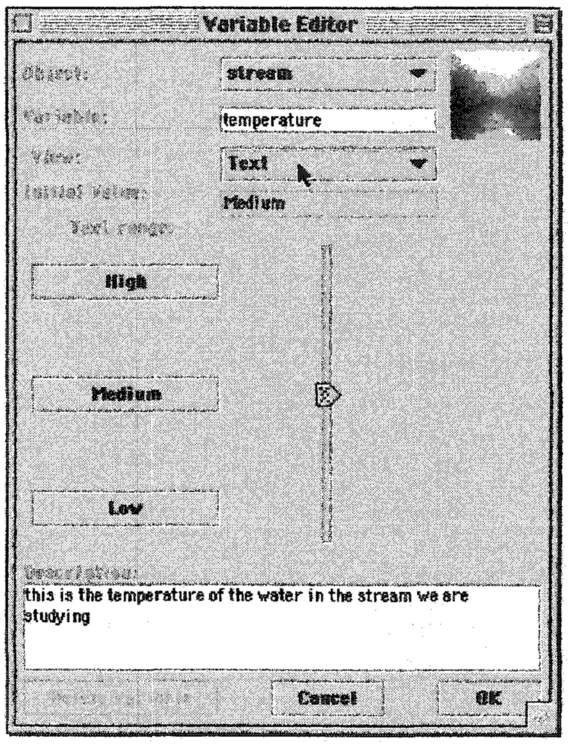



*Figure 3. 3* Defining a variable qualitatively

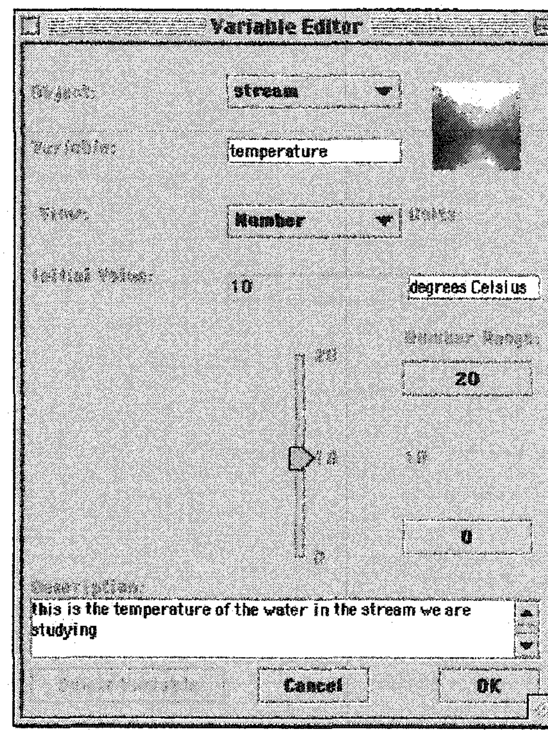



*Figure 3.4* Defining a variable quantitatively

After objects have been identified and variables have been defined, relationships among variables can be created. In the "Build" mode of the software, users create causal relationships by simply drawing an arrow from the variable presumed to be the cause to the variable thought to be affected. Immediately a relationship editor appears in which the user can specify whether the relationship is direct or inverse as well as defining the rate relationship (see Figure 3.5).

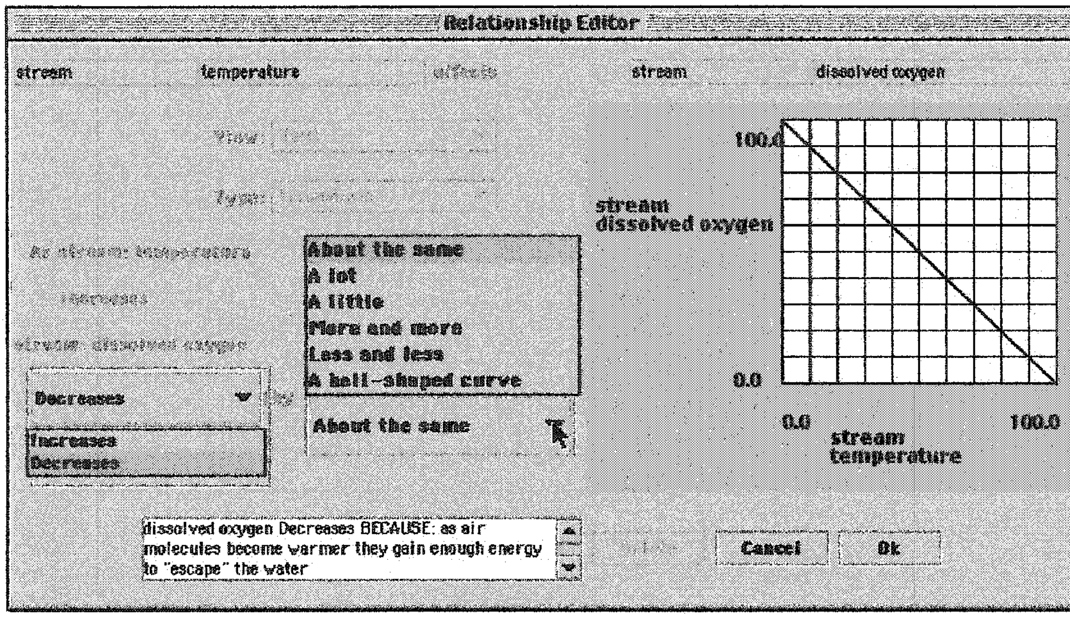



*Figure 3.5* **Describing causal and rate relationships**

Qualitative, verbal representations of relationships are used rather than formal mathematical expressions (Jackson, Stratford, Krajcik, and Soloway, 1995). Given a qualitative textual definition, the software translates the text into a quantitative, visual representation (Jackson, Stratford, Krajcik, and Soloway, 1995). Users are also prompted to explain the rationale behind the relationships that create. This is achieved by means of a dialog box (located at the lower left-hand portion of Figure 3.5) that automatically inserts the variables being related and allows the user to complete the incomplete statement related to the causal relationship. Once relationships have been established among variables, the user can move into "Test" mode. Here, the model can be used as a simulation to allow the performance of thought experiments in which causal variables can be manipulated via sliders. See Figure 3.6 for the effects of using meters and graphs.

Being able to run the model as a simulation provides the opportunity for students to refine and revise their mental models of how the system should behave by comparing the interactive feedback they initiate and receive with the feedback they expect to receive (Jackson, Stratford, Krajcik, and Soloway, 1995).

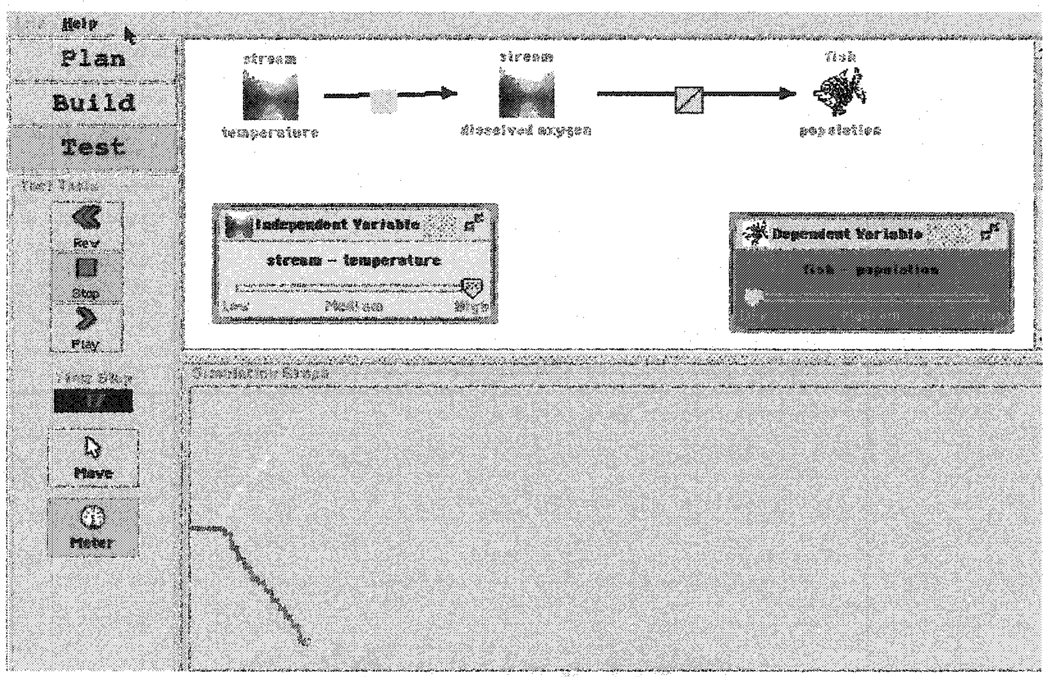



*Figure 3.6* **Testing a model**

### 3.3 The Scientific Modeling Module

There are essentially three aspects of scientific modeling that we wanted to emphasize throughout the modeling module: model-based reasoning, the nature of scientific models, and the notion that modeling is an iterative process. In model-based reasoning, a target system that contains numerous positive analogies with the actual system under study is investigated. Learning about the target provides insight about the behavior of the real system. If the model behaves enough like the actual system, the behavior of the actual system can often be predicted. Regarding the nature of the scientific models, they come in a variety of forms. Models can be physical, conceptual, or mathematical (American Association for the Advancement of Science, 1989). Modeling is an iterative process. The prediction made by a model must be compared with the behavior of the actual phenomena. The model must be revised if it does not agree with observations of nature. In many cases, multiple models for the same system are utilized. Each model is based on some similar and some different initial conditions or assumptions.

The SCIED 410 course was designed to utilize technology-rich environments to support prospective science teachers in learning science content and about the nature of science and scientific inquiry via authentic scientific investigations. The modeling module occurred over seven 90-minute class sessions. Table 3.2 provides an overview of the instructional goals and activities during each session of the module.

### 3.3.1 Session #1

During the first class session the prospective science teachers were introduced to pond ecology and the driving question associated with the module. The driving question was, 'what would happen to the fish in a pond in a wooded setting if the trees around the pond were suddenly cut down thus exposing the pond to more sunlight?' A pond ecosystem was chosen due for two reasons. First, a pond ecosystem provides a suitably complex system that lends itself to simulation modeling. Second, there was a location close to campus where two ponds, one in a wooded and one in a more open setting, could be accessed for field study.

**Table 3.2**

*Scientific Modeling Module Instructional Sequence*

| Session Number (Date) | Title | Description | Goal |
|---|---|---|---|
| 1 (3/28/2002) | Introduction to pond ecology and the driving question | Pond ecology "jig-saw" activity | Gain familiarity with essential components of pond ecosystems |
| | | Discussion of driving question | Understand the "problem" modeling will be used to address |
| 2 (4/2/2002) | Introduction to Scientific Modeling and Pond Study Data Collection techniques | Sharing researched models from various fields | Begin to consider the variety of phenomena scientists use models to study |
| | | Discussion of characteristics of scientific models | Learn characteristics common to scientific models |
| | | Pond Data Gathering techniques | Learn to use MBLs to measure temperature, pH, dissolved oxygen and to determine a biodiversity index |
| 3 (4/4/2002) | Field Study at Pond #1 | Gather biotic and abiotic data at a pond in a wooded setting | Collect data to use to form the basis for computer models |
| 4 (4/11/2002) | Introduction to Model-It and Computer Model Building Session #1 | Learning to us Model-It | Learn to use Model-It to build dynamic computer models |
| | | Building and Testing Computer Models of the Pond | Construct a working model of the pond in the wooded setting and make predictions about the pond in the non-wooded setting |
| 5 (4/16/2002) | Field Study at Pond #2 | Gather biotic and abiotic data at a pond in a non-wooded setting | Collect data to use to revise computer models of the non-wooded pond |
| 6 (4/18/2002) | Computer Model revision | Revise computer models | Learn how models are revised after being compared to real-world systems; in essence model-based reasoning |
| 7 (4/23/2002) | Presentation of Computer Models | Present computer models to the class | Learn how different initial assumptions and relationships determine the behavior of the model |
| | | Discussion regarding the use of scientific models by scientists to learn about complex systems | Learn how important models are to scientists in learning about complex systems that can't be studied any other way |

This particular group of prospective science teachers represented numerous science disciplines. Of the seventeen prospective science teachers in the class (16 of whom agreed to participate in the study), seven were preparing to teach biology, four Earth and Space science, three physics, two chemistry, and one elementary. No assumptions about prior knowledge of freshwater ecosystems were made. Prior to the first class session, prospective science teachers were asked to read one of four passages related to freshwater ecosystems from Freshwater Ecology. The idea was to have groups of prospective science teachers develop a little expertise via the reading and then when they would come to class, each would share their expertise with the rest of the class via a "jig-saw" activity. The chapters provided information on the following topics: basic principles of freshwater ecology, an introduction to the limnology of lakes and ponds, plant and animal life in lakes and ponds. In addition to actually doing the reading, the prospective science teachers were asked to make an outline of the key points from the section they were asked to read.

During the first class sessions, the prospective science teachers were divided into groups composed of at least one "expert" in each of the four areas represented by the readings. They were then asked to share information with each other using the outlines they produced as prompts. After each member of the group had a chance to teach the other members of the group, I presented the driving question. I framed it as if I owned a pond that I stocked with fish for my own recreation and relaxation. I presented the following scenario. My children had asked me if they could use the pond for swimming and I was considering clearing the trees around the pond to make it more amenable to its new purpose but I wanted to consider the ecological repercussions of such action.

Prior to approaching the problem is search of an answer, it would be necessary to consider some of the biological and physical interrelationships in the pond. My area of expertise is actually physics, so I asked a colleague, an environmental educator, to come into the class and provide assistance in getting the prospective science teachers to consider the many relationships that exist within a pond ecosystem. The environmental educator, Roy, led a discussion in the class contrasting biotic verses abiotic factors associated with the stream.

Following this discussion I revealed to the students that we would be using modeling software to address the driving question. As an assignment, they were asked to research modeling in their own field. Students were asked to bring a written description to class summarizing what they were able to learn to share with the class.

**3.3.2 Session #2**

To begin the second session in the module, the prospective science teachers were again divided into groups for the purpose of sharing information about the modeling they researched in their respective fields. They were given the additional instructions to generate a list of common questions or attributes of the modeling to share with the entire class. After allowing sufficient time for them to do this, each group was asked to present their list. After allowing each group to do so, I supplemented this information with information from an article by Van Dreil and Verloop (1999b) in which they elaborate a list of characteristics to scientific models. The authors compiled the following list from a review of relevant literature on the topic:

- A model is always related to a target, which is represented by the model. The term "target" refers to a system, an object, a phenomenon or process.
- A model is a research tool that is used to obtain information about a target that cannot be observed directly. Thus a scale model, that is, an exact copy of an object on another scale, is not considered to be a *scientific* model.
- A model cannot interact directly with the target it represents. Thus a photograph or a spectrum does not qualify as a model.
- A model bears certain analogies to the target, thus enabling the researcher to derive hypotheses from the model that may be tested while studying the target. Testing these hypotheses produces new information about the target.
- A model always differs in certain respects from the target. In general, a model is kept as simple as possible. Dependent on the specific research interests, some aspects of the target are deliberately excluded from the model.
- In designing a model, a compromise must be found between the analogies and the differences with the target, allowing the researcher to make specific choices. This process is guided by the research questions.
- A model is developed through an iterative process, in which empirical data with respect to the target may lead to a revision of the model, while in a following step the model is tested by further study of the target.

(The preceding list was adpapted from: van Driel & Verloop, 1999b; Van Hoeve-Brouwer, 1996; De Vos, 1985)

An overhead was created and the list reviewed with the prospective science teachers.

Following this activity, the prospective science teachers worked through three different stations to prepare them for a field study of the wooded pond. At the first station I demonstrated the use of MBL, pH, temperature, and dissolved oxygen probes. The prospective science teachers first calibrated the probes and then made measurements to practice using the probes. At the second station the environmental educator, Roy, worked with prospective science teachers by demonstrating a technique for determining a biodiversity index for the pond. Using "Stream in a Classroom" equipment, the students used fishing poles with magnets for hooks and in a certain amount of time "hooked" as many organisms as they could. The organisms were turned face down on a long canvas painted to look like a stream. Each organism had a magnet on its back. Once the time limit had been reached, the prospective science teachers placed the name of each organism as it was collected in a grid. By counting continuous runs of similar organisms and dividing by the number or organisms collected, the biodiversity index was calculated. The third and final station consisted of a computer projection system containing a power point presentation entitled "Critters I have known and loved" developed by the environmental educator. The prospective science teachers were asked to view the presentation and begin to consider predator-prey relationships that might exist among the organisms depicted. As an assignment, they were asked to brainstorm relationships that exist among both biotic and abiotic factors in the pond.

### 3.3.3 Session #3

The third session in the modeling module took place at the first of the two pond sites, the wooded pond. The prospective science teachers were arranged into groups and asked to participate in the collection of a variety of biological and physical data collection. They were asked to record the following:

- weather conditions
- make a map of the site and areas sampled

- watershed features including predominant surrounding landscape, local watershed pollutions, watershed erosion
- riparian vegetation within an 18 m buffer
- pond features
- canopy cover
- large woody debris
- plant debris
- aquatic vegetation
- water quality
- organic substrate components

The date of data collection was April 4 and it was quite cold. Some of the prospective science teachers brought chest waders and actually entered the nearly freezing water to collect specimens for the biodiversity index calculation. Because of the inclement weather, it was decided that each group would collect one section of data and the data pooled.

**3.3.4 Session #4**

During the fourth session, the students brought the relationships they brainstormed with them. I then introduced them to the Model-It software using a tutorial that appears on-line. Once this introduction was complete, the students were divided into groups and asked to build a model of the wooded pond and use the model to make a prediction of what would happen to the fish in the pond if the trees around the pond were cut down. The prospective science teachers worked for approximately 1 hour on their models. Since it would be nearly impossible to actually count the number of fish in the pond, the prospective science teachers were asked to identify other predictions their models would make. In this way, they could gauge to what extent their model was behaving like an actual pond.

### 3.3.5 Session #5

During the fifth session in the module, we returned to the pond site but this time to a different pond, one in an open setting not surrounded by trees. The prospective science teachers collected the same data as had been collected at the wooded pond. Two major differences were noted. First, the pH of the open pond was quite different. Second, the open pond had a significantly higher biodiversity index but no fish. A pond is a fairly complex ecosystem. After the prospective science teachers had completed their data collection Roy and I interviewed the owners of the ponds to gain historical perspectives about the two ponds.

### 3.3.6 Session #6

During the sixth class session, the videotaped interviews with the owners were played for the prospective science teachers and they were asked to revise their models based on the differences they encountered at the second pond and the information provided in the interviews. The prospective science teachers were asked to be prepared to present their revised models to the class at the next session.

### 3.3.7 Session #7

During the seventh and final class session of the module, the prospective science teachers shared their revised models with the entire class via computer projection. Each group in turn, presented their model highlighting its features and discussing how they had been revised and what their model predicted. I used the presentations as an opportunity to discuss scientific modeling, specifically the use of computers in modeling with the class.

At this time I read a correspondence I had with Nobel Laureate Russell Hulse in which he shared his ideas about the importance of modeling in science.

**3.4 Summary**

In this chapter I have provided a rationale for the design of the modeling module and described the module in detail. In the next chapter I will describe the methods of inquiry that informed the design, data collection and analysis of this research.

# Chapter 4

# METHODS

## 4.1 Overview

The methods of inquiry that informed the design, data collection and analysis of this qualitative research will be discussed in this chapter. To begin, I will provide a rationale for my choice of design, a case study. This will be followed by detailed accounts of how the data were collected and analyzed. Case study research does not claim any particular methods for data collection or data analysis (Merriam, 1988). As such, multiple data sources and methods of analysis were utilized in this study. Merriam suggested that the qualitative researcher is the primary instrument for data collection and analysis (1988). This was especially true in this study, since I served simultaneously in the role of the researcher and the primary instructor during the events under study. I have therefore included a discussion of my roles as researcher/ instructor. Following the discussion of my role as researcher I discuss the methods I employed to analyze the data. Analysis proceeded in the manner that was most likely to shed light on the research questions (Yin, 1989). Finally, I discuss procedures I followed to enhance the quality of my research.

## 4.2 Research Design: An Interpretive Case Study

For this study a case-study design was selected. Yin defines a case study as (a) an empirical inquiry that (b) investigates a contemporary phenomenon within its real-life context when the boundaries between the phenomenon and its context are not clearly evident and (c) one in which multiple sources of evidence are used (1989). The instructional module was comprised of numerous events and it was hoped that the entire experience would have a positive influence on the prospective teachers' scientific modeling understandings. The phenomenon under study was inextricably tied to the context and there were many variables interacting. It would have been virtually impossible to tease out specific factors or variables such as the computer modeling or a discussion about models in science to identify causal relationships between those activities and changes in understandings. Case study research concentrates on many, if not all, of the variables present in the phenomenon (Merriam, 1988). I endeavored to examine what happened during the module in the hope of gaining insight into the understandings of the prospective teachers who participated in the module throughout the instructional period, how they approached building and testing models, and the kinds of models they built.

Creswell defines a case study as an exploration of a bounded system or a case (or multiple cases) over time through detailed, in-depth data collection involving multiple sources of information rich in context (1998, p. 61). My study centered on a case of prospective science teachers engaged in learning about scientific models and modeling via their participation in an innovative instructional module involving building and testing dynamic computer models.

## 4.3 Data Collection

In this section I describe the methods I utilized for collecting data. I begin with a description of the manner in which the participants in this study were selected followed by a description of the primary and secondary data sources and how they were acquired.

### 4.3.1 Human Subjects

All of the prospective teachers enrolled in the course were invited to participate in the study. During a class session prior to the beginning of the study, the purpose of the study was explained as well as the time commitment required for participation. The only activities potentially required of participants above and beyond normal participation in the course activities were two interviews, prior to and after the instructional module. After the invitation was made, the prospective teachers were asked to complete a Human Subjects Consent Form (see Appendix A). Of the 17 prospective teachers enrolled in the course, 16 agreed to participate.

### 4.3.2 Sampling

The context for this study was described in detail in chapter 3 of this thesis. Purposeful sampling was used to select participants for the study. Potential participants were prospective teachers enrolled in SCIED 410, *Technology Tools to Support Scientific Inquiry* at the Pennsylvania State University during the spring semester of 2002. A minimum of 8 participants (4 pairs) was deemed necessary to provide a rich data set with which to pursue the research questions. That number was appropriate based on the physical setting in which data collection occurred. A balance needed to be struck between meeting the demands of the research I proposed and the constraints of the physical setting of the data collection. However, I contend this sample is more than adequate, as it constituted 50% of the available participants.

The physical setting for the model building and testing was a computer lab containing 16 microcomputers and very little additional space. One important form of data for this study was process video. Process video entails videotaping a computer monitor while simultaneously recording participants' conversations while using the computer. This data collection method has been used for some time and was first described by Krajcik, Simmons, and Lunetta (1988). Process video data were collected for four pairs of prospective teachers building and testing computer models. This number allowed me to set up four video cameras and microphones around the room. Four set-ups did not overcrowd the room and permitted me to move around the room and monitor both the modeling activities of all of the prospective teachers in the class and the recording equipment. By spreading the four set-ups around the room I minimized the amount of audio "bleeding" among the numerous groups working simultaneously. It was anticipated that the participants' faces would not be captured in the video (the computer screen was the focus). Therefore, it was decided that each pair would consist of one male and one female, thus making distinguishing between the two speakers easier for the purpose of transcription.

Participants were selected to be representative of the entire group of prospective teachers enrolled. To achieve such a sample, an open-ended pre-questionnaire was used. All of the prospective teachers enrolled in the course completed a questionnaire we used in our previous research (Crawford & Cullin, 2002) [See Appendix B]. Using the classification scheme (discussed in Chapter 2 of this thesis) developed by Grosslight et al. (1991), the prospective teachers were categorized as possessing level I, II, or III modeling understandings. To enhance validity of the initial assessment of the prospective teachers' understandings, two other researchers familiar with the Grosslight et al. classification scheme also examined the pre-questionnaires and categorized the prospective teachers' understandings. Collectively, we determined that all of the prospective teachers possessed either Level I or II modeling understandings. We decided to pair students (one female and one male) to create the following 4 combinations: a group consisting of 2-Level I modelers, two groups with both a Level-I and Level-II modeler, and one group with 2-Level II modelers. Based on the conditions set forth in my Human Subjects proposal (see Appendix A), I was not permitted to know the identities of the students who had agreed to participate in the study. One of the other researchers, who had also examined the prospective teachers' pre-module questionnaires, chose participants randomly from among those prospective teachers who had agreed to participate in order to create the combinations we had specified at the outset. The sample included four prospective biology teachers, one prospective chemistry teacher, one prospective physics teacher, one prospective Earth & Space science teacher, and one prospective elementary teacher.

### 4.3.3 Data Sources

The computer models generated by prospective teachers, process-video of the act of generating those models, and pre- and post-modeling interviews and questionnaires served as the primary data sources. Secondary data sources included videotaped class sessions, instructor's personal reflections after each session, and artifacts generated by the prospective teachers. In a study such as this, part of what I endeavored to do was to create a rich, thick description (Lincoln & Guba, 1985; Merriam, 1988) of the events of the module as they unfolded. The secondary data sources served as records that I could access to ensure that my descriptions were consistent with the events as they actually unfolded. A timeline of the instructional module displaying when each data source was collected can be viewed in Appendix C of this thesis.

The pre/post questionnaires and pre/post interviews were the primary data sources for addressing research question #1: *What are prospective science teachers' understandings of scientific models and modeling, and in what ways do they change during modeling tasks that include building and testing computer models of pond ecosystems?* The questionnaire was identical to the one we used in a previous study (Crawford & Cullin, 2002). The questions were as follows:

1) What is a scientific model?
2) What is the purpose of a scientific model?
3) When making a model, what do you have to keep in mind or think about?
4) How close does a model have to be to the thing itself?
5) Would a scientist ever change a model? If so, why? If not, why not?
6) Can a scientist have more than one model for the same thing? If so, why? If not, why not?
7) Is teaching about models important in your area of science? Why or why not?
8) Do you intend to teach students about models and modeling? Why or why not?

The interviews were semi-structured based in part on the participant's responses to the questionnaire for the purpose of member checking (Lincoln & Guba, 1985; Merriam, 1988; Miles & Huberman, 1994) and to provide an opportunity for a more detailed investigation into their understandings. The questionnaires in large part guided the interviews. The questionnaires were administered to each of the participants. I then examined the responses and made notes about points that needed clarification and/or elaboration. I conducted semi-structured interviews based in part on the prospective teachers' responses to the questionnaires and where their interviews led the conversation. As such there were aspects of scientific modeling that would become part of the conversation due to the semi-structured nature of the interviews. Included in the interviews were discussions about the models built and tested by the prospective teachers. The pre-instruction interviews were audiotaped and the post-instruction interviews were video- and audiotaped, a data collection method called process-video, to capture references to the models constructed by the particular PST being interviewed. Each audio and videotape was dutifully labeled and duplicated for analysis at a later date.

The computer models built and tested by the prospective teachers were the primary data source for addressing research question #2: *What is the nature of the models prospective science teachers constructed during the modeling tasks?* During the module, the prospective teachers first built (in one 1-hour session) and then revised (in a second 1-hour session) dynamic computer models using the dynamic computer modeling software Model-It. Immediately after the first session the models created by all of the prospective teachers in the class were saved to a server and backed-up on ZIP disks. The models were also copied onto the hard-drive of a third computer. This process was repeated after the second session. All computer files were appropriately labeled and stored for later data analysis.

Process-video techniques were employed to capture both of the 1-hour model building sessions to address research question #3: *In what ways do prospective science teachers go about constructing models during the modeling tasks?* A video camera was set up behind each pair of participants focused between their heads on the computer screen. An external lapel microphone was fixed to the bottom of the computer monitor in such as a way so as to clearly capture the prospective teachers' conversations while working on their models. This method of data capture has been used in numerous other studies both at the Pennsylvania State University and other institutions involved in Project ASSESS (Kyza, 2001). I carefully monitored the equipment via the use of headsets as the prospective teachers worked on their models to make sure all of the equipment was functioning properly. Each process-video tape was appropriately labeled and duplicated for data analysis at a later date.

Numerous secondary data sources helped to create a detailed record of the instructional activities throughout the module. First, each class session was videotaped. Therefore class discussions and all of my commentary was captured. Second, immediately following each session I either wrote down or videotaped my own reflections. All assignments and artifacts generated by the prospective teachers were collected. Specific details regarding the nature and sequence of the activities in the module can be found in Chapter 3 of this thesis. The artifacts collected were descriptions of models in their field that the prospective teachers had researched, lists of characteristics of models generated during groups discussions during one session, and data collected at the ponds. The timeline the Appendix C clearly displays when each of these artifacts was collected.

### 4.4 Role of the Researcher

In section I describe my role in this study as the researcher and primary instructor. My intent is to clarify my biases by commenting on my past experiences and orientations for these biases have likely shaped my approach to the study and how I have interpreted the data (Creswell, 1998; Merriam, 1988).

I have been a high school physics teacher for 13 years. Throughout my career I have wondered about the relationship between what a teacher knows about their subject and how they teach. Specifically, I have been interested how teachers, who typically have little or no experience doing scientific research, learn how to support the development of students' understandings about and abilities to do science. The typical "lab manual" is not found in the scientists' laboratory as a guide clearly spelling out the procedure to be followed to achieve the desired result. The results are most often unknown in such a setting. There is some empirical research that suggests that there is no correlation between teachers' academic backgrounds and their knowledge of the nature of science (Lederman, 1992). However, the studies upon which that claim is made focused on the quantity of science coursework completed by the teachers not the quality of the experiences *doing* science in their backgrounds. I hold fast to the belief that authentic experiences doing science and time spent considering curriculum and instruction in light of those experiences are critical to one's ability to support students in learning science as inquiry.

In this study, I served in two capacities. First, I was the principal investigator. I was also the lead instructor for the module as well as its primary designer. I had a personal stake in the results of the study. I wanted to see growth in the prospective teachers' modeling understandings. I wanted to see evidence that the instructional module that I helped to design and that I implemented was successful.

### 4.5 Data Analysis

A different method was used to analyze each of the three primary data sources. In this section I will describe those methods and provide specific examples wherever possible. Table 4.1 displays each research question cross-referenced with the source of data used to address that question, the means of data transformation, and the method of analysis.

**Table 4.1**

*Research questions cross-referenced with sources of data, means of data transformation, and methods of analysis*

| Research Question | Data Source(s) | Data Transformation(s) | Method of Analysis |
|---|---|---|---|
| 1) What are prospective science teachers' understandings of scientific models and modeling, and in what ways do they change during modeling tasks? | Pre/Post Interviews with 8 prospective teachers | Transcription of Interviews | Analysis of pre/post module modeling understandings using *a prior* modeling understandings |
| | Pre/Post Questionnaires with 16 prospective teachers | Table for pre/post comparison of questionnaires | |

| | | | |
|---|---|---|---|
| 2) What is the nature of the models prospective science teachers constructed during the modeling tasks? | Computer models built by all 16 prospective teachers | Digital screen captures of models as seen in "build" mode of Model-It | Content analysis of models using a rubric |
| 3) In what ways do prospective science teachers go about constructing models during the modeling tasks? | Process-video of 4 pairs of prospective teachers building, testing, and revising computer models in two sessions | Transcription of conversations time stamped to coincide with video of computer screens | Narrative analysis of "episodes" during model building and testing |

### 4.5.1 Interviews and Questionnaires – Research Question #1

Dey defines data analysis as "a process of resolving data into its constituent parts to reveal its characteristic elements and structure" … in analyzing our data we "transform our data into something it was not" (1993, p. 30). The first step I employed in transforming the data was to transcribe the recordings of the interviews. I personally transcribed two of the sixteen interviews, one pre- and one post-, for one of the participants. A superior typist transcribed the others. I listened to each interview while reading the transcript in order to make sure the transcriber did not misrepresent any of the comments in the transcriptions and in some instances made corrections to the transcripts.

Once satisfied that the transcriptions were accurate, I utilized a strategy described by Merriam involving reading through each transcript from beginning to end. While doing this initial read-through or scan I made notes, comments, and queries in the margins (Merriam, 1998) . These "first-pass" notes allowed me to identify the most interesting and important aspects of the interviews. Goetz and LeCompte suggest that, "The notes from taken while scanning constitute the beginning stages of organizing, abstracting, integrating, and synthesizing, which ultimately permit investigators to tell others what they have seen (1984, p. 191)." In order to manage the notes I cut and pasted important or interesting comments made by the interviewees (along with their line numbers and other identifying information) into another document along with my own notes and comments. Table 4.2 shows two sample excerpts from Jane's pre- and post-module interviews that are representative of the notes I made during my first pass over the interview transcripts.

**Table 4.2**

*Excerpts from first pass over Jane's pre- and post-module interviews*

| **Jane notes from pre/post interviews** | |
|---|---|
| **PRE** | **POST** |
| ** implications; where are PSTs likely to be... distinguish between models used for teaching vs. models used for research<br><br>scientists use models to show (this is still the fundamental purpose they see in models... to show or teach)<br>*"If one was, if one was trying to teach a class about, like a high school class about something it would be different for one. Trying to teach a group of scientists something."* (Jane, pre-interview, 3/28, line179) | ** I asked all of them about whether or not a model can be trusted or how do you know if a model is a good one... look at this.<br><br>model validation/trusting models:<br>*"I don't know that you can 100% trust what a model predicts. But I guess if it, if it makes predictions other predictions and you find that those turn out to be true I guess the hypothesis that you test . . ."* (Jane, post-interview, 5/2, line 60)<br><br>** it doesn't seem to me that she understands MBR |

In general codes are used in qualitative research in order to retrieve and organize chunks of descriptive or inferential information (Miles & Huberman, 1994). This research is organized around an educational context in which the development of certain understandings was the instructional objective. It was important to develop a means for identifying to what extent those understandings were evident prior to and following the instructional module. Therefore, an *a priori* list of essential modeling understandings was generated from existing research on modeling understandings (see Chapter 2 of this thesis). I refer to these essential understandings as *dimensions of modeling understandings*: forms of models, the purpose of models, building models, changing models, multiple models for the same thing, and validating models.

After initially scanning each interview as described above I examined each interview transcript and identified comments that pertained to the six dimensions of modeling understandings. The interviews were semi-structured and therefore discussions related to any one dimension did not necessarily occur in any order. It was also not uncommon for topics to be discussed numerous times throughout a given interview. Whenever possible I attempted to prompt the prospective teachers to elaborate on their responses. It was important, especially in the pre-module interviews to determine how they viewed models to be used by scientists. The following excerpt is an example of how I used follow-up questioning to gain access to Carl's views on the purpose of models:

M: To the complex humans we are today. The purpose is to make people aware of evolution as well as the principal of natural selection. So if you could, could you kind of elaborate on what makes this a model?

C: Just like . . . I don't know. It's like whenever we learned it in school like they had it broken down. Like one part was evolution and then natural selection was another part. And just how like they show it like you know like they had the pictures of like natural selection with like the giraffes with the long necks and the giraffes with the short necks and then over time the trees got taller so the giraffes with the long necks could get the leaves. And just stuff like that that made me think of like how you now back whenever I was in school how they taught certain things to us and how I remembered things that were like taught with like pictures and models better than like just reading.

M: Okay. Is this a, is this a model that scientists use?

C: I don't know if they use it but they probably came up with it . So I don't know if they just came up with it to teach it or if it's like the model they use.

M: How do you think the scientists use a model?
C: Probably . . . I don't know. Probably like the other day in class how we started like with brainstorming like a whole bunch of stuff and then like breaking it down into smaller, smaller topics. That's probably how they use like come up with the models and then they use them just the way we do like to . . . (Carl, pre-interview, 4/1/02, line 34)

To aid in the process of identifying comments about a specific dimension of modeling, I utilized a blank table while reading through the interviews during this stage of analysis like the one shown in Figure 4.1.

What does ___CARL___ have to say about the following dimensions of modeling?

PRE/POST

| Dimension | Comments |
|---|---|
| Kinds of models | |
| Purpose of models | |
| Designing/Creating models | |
| Changing models | |
| Multiple models for the same thing | |
| Testing/Validating models | |

*Figure 4.1* **Example of a form used for identifying and organizing prospective teachers' understandings of dimensions of modeling.**

Summaries of comments, their line numbers in the transcript, and my own notes and comments were logged by hand onto the table. After completing the examination of each transcript in this way, a rich, extensive narrative was generated for each participant that described his or her pre- and post- modeling understandings for each dimension. While creating the narratives, I referred back to the notes that I had made during the initial scan of the interview transcripts to make certain that I had not missed any important comments. An example of a section of one of these narratives is included here:

> Jean's Pre-Module View of Models (rating: 2)
>
> Prior to the outset of the module, Jean's view of models was rated as pre-scientific. Jean had very little to say about how models are validated or tested. When discussing this aspect of models and modeling she made reference to hypothesis testing, a prevalent means for establishing the legitimacy of scientific explanations and one that can be associated with modeling. Her reference was more related to science in general though:
>
> > M: I mean how do they know that their model is, explains the phenomenon?
> >
> > J: I think what most scientists, well from what I understand, is that they don't necessarily try to prove something. They try to find things to negate something to like make it not work. And until they find something that shows that it wouldn't, that their theory isn't right and until there's an instance that, that shows that it (the mechanical arm) does bend that way I think they would take that as, as what is common. (Jean, pre-interview, 3/29/02, line123)
>
> Jean's view of *validating/testing models* was rated as pre-scientific. It is scientific in the sense that modeling can include hypothesis testing but a model itself is validated while it is being developed via its agreement with empirical observations.

The narratives can be viewed in their entirety in Chapter 5 of this thesis

To address the first research question, "What are prospective science teachers' understandings of scientific models and modeling, and in what ways do they change during modeling tasks that include building and testing computer models of pond ecosystems?" a rating system was devised. This system was based in part on the seminal work of Grosslight, Unger, Jay and Smith who identified three general levels of modeling understandings of middle and high school students and experts, reflecting different epistemological views about models and their use in science (1991). Some researchers have criticized this 3-level classification system as too broad. Justi and Gilbert (in press), investigating in-service teachers' modeling understandings, concluded that teachers do not display the kinds of stages or levels identified by Grosslight et al. Instead, they suggested that teachers show understandings made up of positions within a series of distinguishable but inter-related aspects of models and modeling. Independently supporting this criticism, Harrison blended Grosslight's levels in order to account for modeling understandings that appeared to be between levels (2001b). For example, Harrison rated some of the inservice teachers in his study as Level 2/3 and others as Level 1/2.

In the present study I expanded and refined the three-level Grosslight, et al. rating system. The new system utilized a matrix of five inter-related dimensions of modeling understandings and four levels of understandings for each dimension. The dimensions of modeling on which I chose to focus were imposed *a priori* as those understandings considered to be scientific or expert-like. The other levels (1, 2, and 3) however emerged from the data. Ultimately, the system consisted of four levels that made it possible for me to discern subtle, yet important differences in modeling understandings. A table displaying each dimension and the four levels of understanding for each dimension can be found in Appendix D. The four levels include the following:

Level 1 – limited
Level 2 – pre-scientific
Level 3 – emerging scientific
Level 4 – scientific

Originally, I used six dimensions of modeling understandings identified from the literature. I collapsed these into five dimensions. The two dimensions, forms of models and the purpose of models, were so intimately linked, that there was nothing to be gained from distinguishing them as separate categories. Modeling understandings were identified and assessed by assigning a level distinction for each participant for each dimension. Table 4.3 illustrates the ratings for one of the participants:

**Table 4.3**

*Example of ratings for one participant.*

| | pre-module understandings | | | | post-module understandings | | | |
|---|---|---|---|---|---|---|---|---|
| **DIMENSION** | **1** | **2** | **3** | **4** | **1** | **2** | **3** | **4** |
| **PURPOSE OF MODELS** | √ | | | | | | √ | |
| **BUILDING MODELS** | | √ | | | | | √ | |
| **CHANGING A MODEL** | | √ | | | | √ | | |
| **MULTIPLE MODELS FOR THE SAME THING** | | √ | | | | √ | | |
| **VALIDATING MODELS** | | √ | | | | | √ | |

The ratings for each participant and subsequent discussion can be viewed in Chapters 5 and 6 of this thesis respectively. To assure consistency, I rated the prospective teachers' understandings twice, once initially and then a second time approximately one month later. During the second rating I adjusted two of the ratings I had made during the first rating due to what I had perceived to be incorrect ratings. In one case the prospective teachers' rating for a particular dimension was rated higher and in the other it was rated lower.

One problematic aspect of rating the prospective teachers' understandings involved those instances during which they expressed multiple views. For example, when initially asked about the purpose of models in science Matt suggested that models were used by teachers as aids when explaining concepts that are difficult to view directly such as the entire solar system. Later, when pressed to consider scientists uses he made a reference to "hypothetical representations" that scientists might use to develop theories. Matt could not provide any examples though. The view of using models as tools to aid in your own theory development is a more scientific view than the view that models are used to explain something to someone else. I was confronted with deciding how to rate Matt's views. In cases such as this, I chose the rating that was most consistent with what I perceived as the participant's most strongly held and expressed view.

As primary instructor and instructional designer of the modeling module, I had a personal stake in seeing modeling understandings becoming more scientific. The question arose, were my methods sufficient to minimize the effects of my bias as the module instructor? To address this question, I enlisted the help of another researcher to act as a peer reviewer to provide an external check of my methods (Creswell, 1998; Lincoln & Guba, 1985; Merriam, 1988). The environmental educator who had provided some of the instruction during the module agreed to serve in this capacity. He reviewed both a pre- and post-module interview transcript for one of the prospective teachers (Carl) and rated his modeling understandings. The environmental educator was quite familiar with my research. We co-authored a paper at the 2003 International Meeting of the Association for the Education of Teachers of Science based on the context of the study upon which this thesis is based (Cullin, Boyle, Crawford, & Zembal-Saul, 2003). He was therefore quite familiar with the nature of the study. Prior to him analyzing the interviews I provided him with a table (Appendix D) that articulated what constituted views of differing levels for each of the dimensions of modeling understandings. The environmental educator rated the prospective teachers' understandings the same or higher than I did in each dimension for both the pre- and post-module interviews. In a discussion after he completed his rating it was revealed that he looked for any evidence of a particular view and rated the prospective teacher based on the view they expressed that was most scientific. His rationale was different than the approach I used of rating what appeared to be the most strongly held view. A comparison of our ratings suggests I was conservative rather than overly charitable in my ratings.

### 4.5.2 Prospective Teachers' Dynamic Computer Models – Research Question #2

I developed a scoring rubric in order to evaluate and compare the computer models built and tested by the prospective science teachers (see Appendix E). Rubrics are guides used to flesh out relevant criteria and differentiate levels of understanding (Wiggins & McTighe, 1998). I chose to separate the scoring of the models into their qualitative and quantitative aspects. The software Model-It makes use of three basic components: *objects*, the actual physical entities of the phenomenon under study; *variables*, quantities that either qualitatively or quantitatively describe the objects; and *relationships* that describe how variables affect one another. The quantitative aspects of the model will provide an evaluation of the complexity of the model. The qualitative aspects will provide an evaluation of the scientific validity or "correctness" of the model.

In a model constructed using Model-It, the relationships, variables, and objects built into the model are hierarchical. That is, the identification of relationships is more difficult than the identification of variables and the identification of variables is more difficult than the identification of objects. Therefore, I weighted the number of each of these entities as they are found in an individual model accordingly. To derive a "score" for the quantitative aspects of a model; the number of objects was multiplied by 1, the number of variables by 2, and the number of relationships by 3. The complexity of a model is also increased if a given variable is shown to affect more than one other variable. Complex systems such as ecosystems are characterized by many interrelated components. A "better" model should be demonstrative of this. Points were therefore awarded for variables that that were related to more than one other variable.

The qualitative aspects of the model give an indication as to how well the model was constructed and how closely it resembles its target. A pond ecosystem is an incredibly complex system comprised of numerous entities, both macroscopic and microscopic. In our pond study, we pulled samples of organisms from the pond and completed a biodiversity study. Based on the organisms we actually observed, I obtained digital images of those organisms and made them available to the prospective teachers for use in their models. It important to note this, since it may have constrained the objects they chose to include in their models. In any case, there were certain objects that had to be considered critical for modeling the behavior of a pond ecosystem. The evaluation of the models took this into account. *Critical objects* were therefore identified and points were awarded for their inclusion. The same was true of variables; specifically, the pond ecosystem models that were built had to address the driving question, 'what will happen to the fish in a pond in a wooded setting if the trees are cut down?' Certain variables are needed in a model when the purpose of the model is to make a prediction. Therefore *critical variables* were also identified.

Certain objects could have been viewed in broad or specific terms. An object such as fish, for instance, could have been identified as fish (meaning all fish) or different species of fish, such as blue gills or bass. The same would be true for variables. The object fish could have defined for it the variable population only. It would also be possible to include the variables population, health, and size. A model that would have taken such variables into account would be considered more accurate than one that made little distinction between object and variables. To address these nuances, I made a provision for additional objects and variables that could be considered important and appropriate to the phenomenon being modeled.

Perhaps the most important aspects of a model are the relationships contained therein. For creating a model that behaves like its target, accurate relationships must be created. For the pond ecosystem, I identified *critical relationships*. In the rubric, these relationships were assessed in three ways. First, the relationship had to have been identified. Second, the correct causal assumption had to be made. For instance, a relationship between temperature and dissolved oxygen may have been identified. In Model-It, when such a relationship is identified, the user must decide on the causal relationship. In the example of temperature and dissolved oxygen, an appropriate causal assumption is that increasing the temperature of water decreases its capacity for holding oxygen. Scientists explain this relationship suggesting that as temperature increases, oxygen molecules dissolved in the water become more energetic and escape. The third and final component of the relationship, the rate relationship, is a much more difficult aspect of the relationship to define. I have therefore chosen not to include the rate of the relationships in my evaluation of the prospective teachers' models. In Model-It, the manner in which one variable affects another can be specified to some degree of specificity. The number of trees obviously affects the amount of sunlight for instance. But it is extremely difficult to determine exactly to what extent. In Model-It, the one variable can be specified to affect another the same, more, less, more and more, less and less, or along a tolerance curve where it might cause the affected variable to increase to a point and then decrease. In nature, such relationships are difficult to know for certain and beyond the scope of the models we built.

To aid in the scoring and assess the validity of the rubric itself, I built a model that would include all of the critical objects, variables, and relationships. I then used the rubric to evaluate the model. This model received a quantitative score of "45" and a qualitative score of "35." With these scores, I had a basis of comparison and the prospective teachers' models could then be compared accordingly. A digital image of the "standard" model can be found in Appendix F. The completed rubric showing the score of the standard model can be found in Appendix G.

**4.5.3 Process-Video of Models Being Built and Tested – Research Question #3**

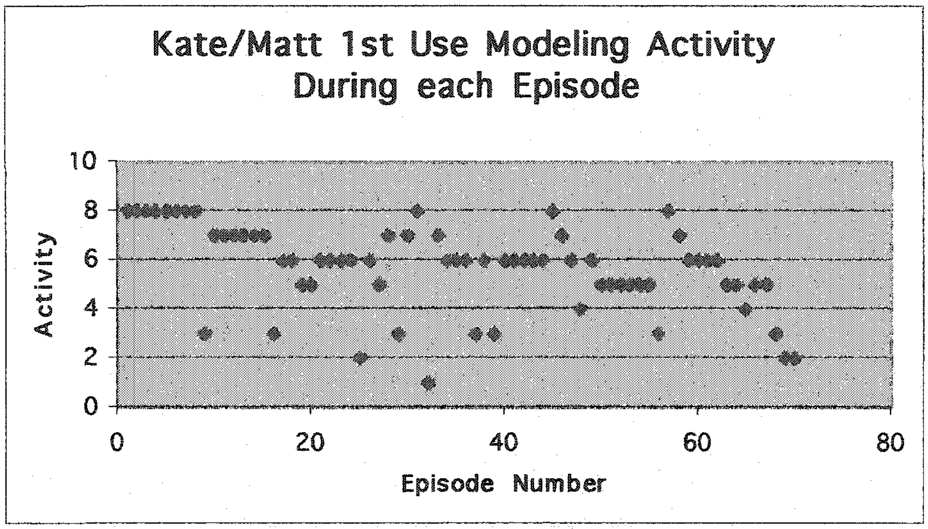
In his dissertation entitled Investigating Processes and Products of Secondary Science Students Using Dynamic Modeling Software, Stratford developed a three-stage method for capturing the quality and characteristics of modeling strategies employed by groups of pre-college students using Model-It (1996, pp. 57-65). He too used process-video as a primary data source. I have modified Stratford's methods based on the nature of my research. He was interested in what the process-video data revealed about students' cognitive modeling strategies. I attempted to determine what the prospective teachers' modeling strategies revealed and perhaps contributed to their understandings of the role of models and modeling in science.

The first step in the analysis of the process video was to transcribe the audio portion. In the first stage, the video and audio were translated into a highly descriptive form. This was accomplished by means of dividing the transcripts into episodes of modeling activity, converting those episodes into descriptive accounts, and then categorizing those accounts. I created a table for each modeling session for each of the four pairs. Each row of the table consisted of the episode number, the transcript of the conversation and/or the activities that occurred during that episode, a description of what occurred during that episode and my own notes. Table 4.4 displays an excerpt of a table from Kate and Matt's first modeling session.

**Table 4.4**
*Excerpt from Kate and Matt's Session 1 Modeling*

| Episode # | Text from Transcript | Description | Comments |
|---|---|---|---|
| 48 | K: Alright, do we have any more objects or variables?<br>M: I think we have enough variables on there that we are already confusing<br>K: I do too<br>M: for the system… OK, run it… oh, that looks good… cut down some trees… nothin, very little effect<br>K: a little bit…we didn't cut down very many… uh-oh, now we confused it… it doen't know what to do<br>M: now add some trees… we had a bunch more trees there… that picked up the blue gill population a little which doesn't make sense because that's adding more shade and decreasing the water temperature<br>K: but it's also raising dissolved oxygen<br>M: but is it testing those variables right now?<br>K: yeah, they're all connected<br>M: are you sure? But when you do this graph simulation, is it measuring anything that isn't up?<br>K: It has to<br>M: here what I'm saying though? Does it show other variables<br>K: I think it's including every relationship we put in there<br>M: let's try it one time… OK, OK… I see what you're saying because you can't really plug in more boxes<br>K: I mean when we did a tree, when we affect the trees we're affecting the water temperature | tested model with new and revised relationships; analyzed and evaluated results | Matt is confused about whether or not relationships are running even when they are not being shown in test mode |

In the second phase, I generated process maps that displayed the activity during each episode. Miles and Huberman suggest the use of data displays to "present information systematically, so the user can draw valid conclusions… (1994, p. 91)." Figure 4.2 shows a process map for a modeling session. In the final stage, I attempted to synthesize the descriptive and analytical data into narratives intended to capture the prospective teachers' understandings as revealed by their modeling strategies.




**Activity Designations**

8 - create object
7 - defined variable
6 - built relationship
5 - tested model
4 - revised model
3 - discussion
2 - questioned instructor
1 - other

*Figure 4.2* **Process Map of Kate and Matt's First Use of Model-It**

**4.6 Addressing Standards of Quality and Verification**

In this section I address standards of quality of verification by comparing recommendations from the literature on qualitative research. In an entire chapter on standards of quality and verification, Creswell distinguishes between the two defining standards as " criteria imposed by the researcher and others after a study is completed" and verification as "a process that occurs throughout the data collection, analysis, and report writing of s study (1998, p. 194)."

**4.6.1 Standards of Quality**

In discussing standards of quality Creswell compares frameworks for assessing the quality of qualitative research. One, advanced by Howe and Eisenhardt (1990), suggests five means for evaluating all research: 1) assess a study in terms of whether the research questions drive the data collection rather than the data driving the research questions; 2) examine the extent to which the data collection and analysis techniques are competently applied in a technical sense; 3) ask whether the researcher's assumptions are made explicit; 4) wonder whether the study is robust, uses respected theoretical explanations, and discusses disconfirmed theoretical explanations; and 5) assess whether or not the study has value in both informing and improving practice and in protecting confidentiality, privacy, and truth telling of participants (Creswell, 1998). I believe I have addressed these standards in my study and will now discuss the measures I have taken to do so.

**Standard 1: The research questions drove the data collection and analysis.**

The focus of my study has been on prospective teachers' understandings of the role of models and modeling in science. Three research questions have guided my research, each contributing unique insight to my understanding of the prospective teachers' modeling understandings. Multiple data sources have been used to address each question.

**Standard 2: Data collection and analysis techniques have been consistently and systematically applied.**

I have been working within the tradition of case study research. Merriam suggested that case study research does not claim any particular methods for data collection or data analysis (1988). While subscribing to that view, I have not collected and analyzed data in a reckless or haphazard way. In many instances I have used developed unique means for finding meaning in the data such as the development of the system for rating the prospective teachers' modeling understandings, the development of a rubric for comparing the models they build, and the development of process maps for identifying the different approaches taken by the prospective teachers in building their models. In all efforts I have employed careful, systematic approaches designed to address the research questions I have posed and in consideration of the data I collected.

**Standard 3: I have made my orientations and biases explicit**

In section 4.4 of this chapter I discussed my role as a researcher in this study. I explained my orientations to teaching and my concerns regarding biases that needed to be addressed resulting from my dual role as researcher and instructor. In doing so I have made the reader aware of my subjectivity.

**Standard 4: This study is based in and discusses respected theoretical explanations**

I have conducted an extensive review of the literature related to understandings of models and modeling in science by examining numerous databases. Although the number of empirical studies is relatively small, the studies reviewed have been published in widely respected journals such as The Journal of Research in Science Education and the International Journal of Science Education or presented at international conferences and annual meetings of the organizations who publish those journals. In chapter 6 of this thesis I discuss the results of my analysis in light of the empirical research base that has served to guide my research. In instances where there appear to be disconfirmed theoretical explanations, I have endeavored to add my findings to the discussion.

**Standard 5: This study has value and standards of ethics have been upheld**

The goal of every researcher is to contribute to the knowledge base of their chosen field. I believe I have contributed to the field of science education in three areas:

science education research, science teacher education, and science pedagogy. In chapter 7 of this thesis I discuss the implications of my findings in each of those areas. Throughout the study I have attempted to maintain high ethical standards beginning with meeting requirements regarding human subjects as stipulated by the Pennsylvania State University. I have used pseudonyms at all times to protect the anonymity of the participants in my study. I have also attempted to be honest in my evaluation of their modeling understandings.

**4.6.2 Verification**

Qualitative research requires measures to ensure that "good" results are obtained, as do all forms of inquiry. In addition to addressing standards of quality, many qualitative researchers recommend measures for verifying that they "got it right (Creswell, 1998; Lincoln & Guba, 1985for example)." In my study I have employed strategies to ensure that I "got it right." Creswell identified eight procedures for verification: prolonged engagement and persistent observation, triangulation, peer review or debriefing, negative case analysis, clarifying researcher bias, member checks, rich, thick description, and external audits. He recommended that at least two of these procedures be utilized in any study. In my study I have employed four of the eight procedures extensively (prolonged engagement and persistent observation, triangulation, clarifying researcher bias, rich, thick, description) and two of them only in regard to my first research question (peer review and member checks). I will now discuss how I employed these procedures in my research.

My role as instructor of the module and the time period over which it occurred permitted me to have *prolonged engagement* with the participants in the study. The modeling module occurred during the second half of the spring 2002 semester. I had the opportunity to build trust between the participants and myself. I was completely immersed in all aspects of the modeling module and while my biases are a potential limitation of the study, my immersion in the setting should be considered a strength because no other individual could have my perspective on the events as they unfolded. I have attempted in chapters 3,4, and 5 of this thesis to provide a *rich, thick description* of the participants and setting under study. This is especially evident in my having dedicated an entire chapter (Chapter 3) of this thesis to describing the context of the modeling module. In my study I have investigated how prospective teachers' understandings of the role of models and modeling were revealed in their words, models and modeling strategies. Each of the multiple data sources has served as a source of evidence for *triangulating* what I learned from the other data sources. Many qualitative researchers have suggested *clarifying researcher bias* from the outset of a study (Creswell, 1998; Merriam, 1988for example). I clearly stated my subjectivity in section 4.4 of this chapter.

In Research Question #1 I examined prospective teachers' understandings of the role of models and modeling in science. I utilized two procedures to enhance the results of my analysis and improve the accuracy of my work. First, to address my biases I made use of *peer review* by seeking the help of a fellow researcher who helped me to be sure I was not rating the prospective teachers understandings too highly. Second, I utilized a form of *member checks* during the pre- and post-module interviews of my interpretations of what the prospective teachers' wrote on questionnaires. I asked them to clarify what they had written and in some instances stated my interpretation of their meaning and allowed them to confirm or deny it.

**4.7 Limitations of the Study**

This study has lead to several interesting findings, some of which have not appeared in previous literature. However, I recognize that every study has limitations and it is necessary to discuss them. First, I could have been more confident of my interpretations of the prospective teachers' comments about models and modeling if I had been able to analyze their interviews and do a member check by asking them to confirm that my interpretations were correct. I employed this verification procedure occasionally during each interview by asking them to confirm that my interpretation of their responses to the two questionnaires was correct. While certainly a sound approach, it would have been a practical impossibility for me to undertake the analysis of the pre-module interviews during the module due to the compressed schedule of events. My dual role of instructor and researcher was in the case of this research a double-edged sword. Being the instructor provided me with insight unattainable any other way, even as an observer or participant observer. Unfortunately I was limited by the time I could spend analyzing data during the module due to my role as instructor.

A second limitation involves the fact that I cannot be completely sure if understandings changed or were added to through experiences that occurred during the module. My instructional objectives were to support the prospective teachers in learning about the role of models and modeling in science. I consider knowledge of modeling to be knowledge about inquiry and the nature of science akin to what Schwab referred to as syntactical knowledge (Schwab, 1978). Other aspects of models and modeling in education are equally important such as using models with students and teaching with models. Most of the prospective teachers began with limited views of the nature of models that most likely resulted from their own experiences with teachers using models as instructional aids. This is a limited but not incorrect view of models. The methods I used did not permit me to know if understandings had been replaced or expanded.

A third limitation stems from the fact that I assessed the models and modeling strategies of pairs of prospective teachers rather than individuals. It was necessary for me to proceed in this manner because I needed a means for accessing their thought processes while building and testing models. This limitation has not inhibited me from addressing my research questions but did constrain my ability to formulate conclusions from the interplay among the research questions.

A fourth and final potential limitation concerns all of the explicit attention to scientific modeling in the form of questionnaires and interviews, not designed to be part of the instruction. This is similar to a testing-treatment interaction (Wiersma, 1995). The assessments themselves could have contributed more to changes in understandings, than the treatment itself. However, the purpose of this study was not to establish a causal relationship between the events of the module and the changes that occur. Instead, the purpose of this study was to use the instructional module as a context for examining those understandings in a unique way.

**4.8 Summary**

In this chapter I have identified key decision points and provided a rationale for each. I have also included an in-depth discussion of my data collection and analysis with examples from the data. Finally, I have described procedures I employed to enhance the quality of my research and identified potential limitations of my study. In the next chapter I present the results of my analysis.

# Chapter 5

# RESULTS

## 5.1 Introduction

In this chapter I present the results of my analysis. Each research question will be addressed in turn. To organize the presentation of the results, I have generated profiles of each participant's modeling understandings (for research question 1) and each pair's models and modeling strategies (for research questions 2 and 3). Evidence from the appropriate data sources will be presented to support the interpretations that resulted in these profiles.

## 5.2 Profiles of the Prospective Teachers' Pre/Post Modeling Understandings

The rating system that was described in Chapter 4 of this thesis utilizes the following scale to characterize the prospective teachers' modeling understandings:

1 – limited understandings
2 – pre-scientific understandings
3 – emerging-scientific understandings
4 - scientific understandings

### 5.2.1 Carl

A comparison of the ratings of Carl's pre- and post-module modeling understandings can be seen in Table 5.1.

**Table 5.1**
*Ratings of Carl's Pre/Post Modeling Understandings*

| | pre-module understandings | | | | post-module understandings | | | |
|---|---|---|---|---|---|---|---|---|
| **DIMENSION** | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| **PURPOSE OF MODELS** | √ | | | | | | √ | |
| **BUILDING MODELS** | | √ | | | | | √ | |
| **CHANGING A MODEL** | | √ | | | | √ | | |
| **MULTIPLE MODELS FOR THE SAME THING** | | √ | | | | √ | | |
| **VALIDATING MODELS** | | √ | | | | | √ | |

**Carl's Pre-Module View of the Purpose of Models (rating: 1)**

Prior to the outset of the module, Carl's view of the purpose of models was rated as limited. Carl did not recognize a model as a tool used in the generation of new knowledge. Rather, he viewed models as tools for conveying information about a phenomenon. Carl described a model as a type of flow-chart. The purpose of such a model, according to Carl, would be to make a complex phenomenon more comprehensible through visualization and by displaying a complex phenomenon in its constituent parts:

> Whenever I was writing that I was thinking of like how like you don't study . . . in biology you don't study like photosynthesis and then there's like the Krebs cycle and then there's restoration. You don't study it like in one big chunk. They have like little models that show you how like the enzymes break it down . . . . It's like you have like a word and then like the arrow comes down and then it will have like something written on the arrow that says like the arrow is the enzyme. And the blocks are the products and then it goes around in a circle. (Carl, pre-interview, 4/1/02, line 11)

Carl extended his view described above to scientists' use of models:

> That's probably how they used like come up with the models and then they use them just the way we do like to . . . (Carl, pre-interview, 4/1/02, line 11)

When asked to elaborate on how scientists use models, he ascribed little value to models for helping scientists, favoring instead their utility in helping others understand:

> M (Interviewer):How do you, how do you think they use a model?
> C (Carl):I don't know. Probably just like between like interdisciplinary things like to show better like one thing to another.
> M: Who would they be showing it to? Or if it helps them themselves?
> C: I think it helps them. But then it's, it's easier for them to like show like teachers in other subject areas what they have to do. (Carl, pre-interview, 4/1/02, line 71)

Carl also suggested that a model could be a protocol to follow:

> You can have like steps. Like I know like my mom's a nurse and I'm sure like she has like models that like whenever she goes to like a conference or something I'm sure there's steps like you go through like to like give a shot and like you could use like a model for that like to teach somebody something too. (Carl, pre-interview, 4/1/02, line 71)

Carl's view of the purpose of models was rated as limited since it suggests that a model is a final form entity, published in a textbook for instance, rather than an entity that is actively used by a researcher in generating new knowledge.

**Carl's Post-Module View of the Purpose of Models (rating: 3)**

After the module, Carl's view of the purpose of models was rated as emerging-scientific. Carl still did not recognize a model as a tool used in the generation of new knowledge. He did however appear to have expanded his views in three ways. First, in an extension of his pre-module view of a model as a tool of conveyance, Carl saw value in being able to show all of the intermediate steps in a process:

> Because I think with the mitosis model all you can really do is look at it and see what like, what like with those ones you can only see what happens from phase to phase. But it you built like a simulation for a model you know you could see, you could start it off with the beginning of mitosis and go right to the end. And in between you could see all the things that happened and you could have the model changing like showing the phase as they went through like you know. (Carl, post-interview, 4/29/02, line 162)

Second, Carl briefly discussed using a model in place of the target but still in an educational setting. He referenced using a model in place of student trips to the field:

> So you know that would be useful in classrooms where you can't take a field trip of students to the pond. (Carl, post-interview, 4/29/02, line 228)

Finally, Carl mentioned on a few occasions using models to see what might happen to a system under various conditions. He used the terms predict and show synonymously. In some instances it was clear that the phenomenon was completely understood:

> I think, I'm sure they just use it there to predict the outcome of what happens in like cellular respiration. (Carl, post-interview, 4/29/02, line 44)

In others, the outcome of events may have been uncertain:

> . . . like you know if people wanted to know what was going to happen with their pond model or what would happen with their own pond you could just show them with the model what would be predicted and then you know . . . before like even in places like say a factory were going to be around the pond, you could show what would happen if like an increase of pollution came in. So there's a lot of different things you could do by just having a model where, where it would be just as good as like if you were at the pond. (Carl, post-interview, 4/29/02, line 44)

Carl's view of the purpose of models was rated as emerging-scientific because he clearly identified a model as a tool used to obtain information about the target. He recognized the capability of using models to explore what might happen to the target if conditions were changed. His views are not scientific since he did not appear to recognize modeling as a means for figuring out how the target system behaves in the first place.

**Carl's Pre-Module View of Building Models (rating: 2)**

Prior to the outset of the module, Carl's view of building models was rated as pre-scientific. Carl admitted that he was unsure of how scientists use models. Instead, he suggested that they are probably the ones who develop them. He does not appear to recognize that using models and developing models are often one and the same process. Carl described the modeling process vaguely as involving brainstorming and plugging away until scientists come up with what they feel is a good model:

> Probably just by brainstorming and scientists sitting around like plugging away at like what they think should be involved and what they shouldn't, what shouldn't, and actually coming up with what they feel is a good model. (Carl, pre-interview, 4/1/02, line 297)

Carl, adding to his tools of conveyance view of models, indicated that a model has to be close to the thing it represents so that whoever is viewing it will not be misled. He added that this also includes not including extraneous information:

> . . . make sure that the material you're presenting is clear and that it all relates very closely to the material you are trying to convey . . . if you're making a model you want it to be really concise and have just the stuff that you want to convey and not like a whole bunch of like different topics. (Carl, pre-interview, 4/1/02, line 58)

Carl also suggested that the "audience" for the model might mediate the level of complexity or sophistication of the model itself (i.e., different ages or levels of students):

> M: So do you think that scientists start out with a simple model and then use more complex ones?
>
> C: Yeah, like I'm sure they do that. But I was thinking more along the lines of like classroom experience. Like you start learning it in like maybe sixth grade and it's a really simple model. And as you progress each year they like try to add more and more to it. So eventually it's a complex model of the same thing. (Carl, pre-interview, 4/1/02, line 221)

Carl's view of building models was rated as pre-scientific because, although he did not make an explicit connection between building models and observations of nature, he did acknowledge, albeit in a vague manner, that modeling involves an iterative process.

**<u>Carl's Post-Module View of Building Models (rating: 3)</u>**

After the module, Carl's view of building models was rated as emerging-scientific. Carl indicated that the relationships among the variables in a system of interest would have to be accurately represented to have a properly functioning model:

> . . . you have to keep in mind the relationships between things and how changing one thing about the model, how everything else will be affected. (Carl, post-questionnaire)

He made an explicit link between repeatedly observing the phenomenon and building the model in an attempt to get the model to behave like the target:

> Just by going and like looking at your model and going to the pond and looking a the conditions the pond is at and making the settings on your model the same as what the pond was and getting the same results like time after time. (Carl, post-interview, 4/29/02, line 217)

Carl was able to apply these views to current and future systems like the pond and weather predicting. He was unable to apply them to systems that are inaccessible like those that existed in the distant past:

> Because you can't really go back and like look at what happened you know you can't follow along like you could with the weather. You can't say well this is what happened this day and this is what happened this day. (Carl, post-interview, 4/29/02, line 399)

In such cases, he did not describe the same kind of process for models building. Instead he suggested that available data and a logical thought process would need to be used:

> . . . just by like (inaudible) looking at what evidence there was and using that to build your model. (Carl, post-interview, 4/29/02, line 315)

Carl's view of building models was rated as emerging-scientific since he clearly recognized a link between repeated observations of the target and building the model. It is not a scientific view because he does not appear to apply the same process to any modeling situation.

**<u>Carl's Pre-Module View of Changing Models (rating: 2)</u>**

Prior to the outset of the module, Carl's view of changing models was rated as pre-scientific. Carl indicated that scientists change models when new information comes along. He added that in some cases models are changed and in others replaced completely:

> Scientists change models whenever new information comes along. They incorporate this new information into the old model. Sometimes though

> the new data is so different a new model must be made and the old one done away with completely. (Carl, pre-questionnaire)

Carl used the example of fossils of a primitive man whose discovery would prompt scientists to adjust their models of how humankind evolved.

Carl's view of changing models was rated as pre-scientific because, although he readily acknowledged that models are subject to change, he failed to acknowledge the connection between the behavior of a model and the behavior of the target as the reason for that change.

**Carl's Post-Module View of Changing Models (rating: 2)**

After the module, Carl's view of changing models was again rated as pre-scientific. After the module, Carl again expressed the view that models do change based on new discoveries. He used the same example (the primitive man) while explaining how new information would change a model. It could be argued that his post-module views on building and testing models (repeated observations of the target while building the model) implied a change in his views on changing models but he failed to articulate a more scientific view when asked directly.

Carl's view of changing models was rated as pre-scientific because he did not explicitly acknowledge a relationship between changing a model and agreement with the behavior of the target phenomenon. He did not appear to possess a scientific view since he retained the pre-scientific view that "new discoveries" change a model without mention of agreement with observation.

**Carl's Pre-Module View of Multiple Models for the Same Thing (rating: 2)**

Prior to the outset of the module, Carl's view of multiple models was rated as pre-scientific. Carl suggested two reasons for multiple models. First, different authors of textbooks are likely to have "favorite" models, and those are the ones that they will include in their texts:

> So they have their model and you know the one they like. So then they put it in their book. So almost all the models are going to be kind of the same, but you get like variations in them of just how they look in like a textbook. (Carl, pre-interview, 4/1/02, line 217)

Second, Carl indicated that the complexity of a model would make it "different" from another model, and the complexity of a model would be mediated by the audience for whom the model is intended. Thus, models can have different levels of sophistication:

> . . . I was thinking more along the lines of like classroom experience. Like you start learning it in like maybe sixth grade and it's a really simple model. And as you progress each year, they like try to add more and more to it. So eventually it's a complex model of the same thing. (Carl, pre-interview, 4/1/02, line 223)

Carl did mention two models that appeared to be competing models when he was pressed to provide an example of a case where scientists had more than one model for the same phenomenon:

> Like last year in my invertebrates class there were like there's a scientist who like argues over taxonomy of invertebrates, especially like certain groups and phyla. And like some of them don't believe like that some of them are linking them and some of them are in another. So like I'm sure they have like, like one group, whatever they think has like a taxonomic group that shows like you know how like they evolved with the little lines. And then I'm sure like another group has another model that has like the

> same thing but they have them going to different groups. (Carl, pre-interview, 4/1/02, line 184)

Carl's view of multiple models for the same thing would probably be limited because he associated aspects of models related to this dimension primarily with conveying information. He did make a connection between the model and the modeler's ideas (the textbook example). He also provided an example of competing models. As a result, his views were raised to a rating of pre-scientific.

**<u>Carl's Post-Module View of Multiple Models for the Same Thing (rating: 2)</u>**

After the module, Carl's view of multiple models was again rated as pre-scientific. Carl expressed a different view of multiple models than he had prior to the module, but it was no more scientific. Prior to the module, he referred to different levels of complexity or preference as reasons for having multiple models. After the module, he described models that were different in form (e.g., a computer model and a physical model):

> You could have another one just as good or maybe you know in like a totally different context but still being the same model and giving you the same information. And they could both be just as good, but maybe one is on the computer and you know maybe one is in a book. (Carl, post-interview, 4/29/02, line 252)

He again alluded to competing models but was really unable to elaborate on what might make them different:

> Well, if you can find evidence to support it I'm sure it would be just as good as the other two because you know nobody knows for sure. So as long as I guess you could find evidence of whatever, what you were trying to put into your model and use that to build your model, it would have to at least be looked at. (Carl, post-interview, 4/29/02, line294)

Carl's view of multiple models for the same thing was again rated as pre-scientific since, although it was somewhat different, it was not more scientific than those he expressed prior to the module.

**Carl's Pre-Module View of Validating Models (rating: 2)**

Prior to the outset of the module, Carl's view of validating models was rated as pre-scientific. Carl had very little to say about how models are validated or tested. He expressed the view that the scientific community decides if a model is valid. He envisioned that models are passed on to the scientific community via publications:

C: And then they give it to the scientific community and then they pass it on to us who are just like teachers and . . . .

M: So you think a scientist has a, a model of some phenomenon? And how would he, how would he get it to the scientific community?

C: Probably the same process of like having a paper published like you know peer review and stuff. Just a bunch of stuff like that. Sending them out and then going for a review board and them having you ask all kind of questions about why you did it like this and what reasons for everything and you have it explained. And then after that I'm sure it's kind of accepted. (Carl, pre-interview, 4/1/02, line 299)

Carl's view of validating models was rated as pre-scientific. It is scientific in the sense that the scientific community does indeed "judge" the validity of the conclusions formed through the development of models, but the model itself is judged while it is being developed via its agreement with empirical observations.

**Carl's Post-Module View of Validating Models (rating: 3)**

After the module, Carl's view of validating models was rated as emerging-scientific. Carl expressed important views regarding validating and testing models. He acknowledged that the predictions made by a model would be compared to the behavior of the target system.

> Just by going and like looking at your model and going to the pond and looking a the conditions the pond is at and making the settings on your model the same as what the pond was and getting the same results like time after time. (Carl, post-interview, 4/29/02, line 218)

He explained that if the predictions were in agreement that it does not necessarily mean that the model is correct:

> C: I mean just because you get it to match doesn't necessarily mean that your model is working just as the pond.
> M: Okay. Suppose I, suppose I go out there and my model predicted the blue gill population should be high and I go out there and there's hardly any blue gills? What do you think I'd take away from that?
> C: Probably just look at like what factors you missed or like some things that you could have included that you didn't and like just go back and look at everything that contributed to why and there probably wasn't any in the pond and come back and look at your model and see what was wrong with the model. (Carl, post-interview, 4/29/02, line 81)

This is a sophisticated view. Carl also indicated that if the predictions of the model did not agree with observations of the target that something was wrong with the model. He again had a difficult time applying the same principles to situations that were not directly observable, and it is these phenomena for which modeling is so crucial in science.

Carl's view of validating models was rated as emerging-scientific because he expressed quite sophisticated views in certain aspects such as the meaning of agreement or disagreement between the behavior of model and target. His views are not quite scientific since he was unable to apply the same views to all phenomena.

**Discussion of Carl's Modeling Understandings**

Carl's understandings about scientific models and modeling became more scientific in 3 out of 5 dimensions. Prior to the module, Carl viewed the purpose of models as being aids for understanding complex processes or procedures. This view influenced his views of other dimensions. For example, he suggested that decisions on building models were made to ensure that the audience would not be misled. Subsequently, models come in multiple forms of varying complexity. He appeared to understand that model building involves a great deal of time and effort, but he could not describe the model building process. His view of a model was of a final form entity that is changed when "new discoveries" are made.

After the module, aspects of Carl's view of the purpose of models were more scientific than they had been prior to the module. For instance, he expanded his view to include using the model in place of the actual phenomenon. He also recognized that models could be used to explore what might happen to a system under certain conditions. However, he may also have retained certain aspects of his pre-module view of the purpose of models, specifically those associated with using models in educational as opposed to research settings. For instance, he recognized the dynamic aspect of computer models as superior to the pictorial kind he described prior to the module. However, the advantage he described was that a computer model could *show* all of the steps in between what could be shown in static snapshots in a diagram. Regarding building models, Carl recognized the importance of relationships among variables in a model, something that would not have been associated with his pre-module view of a model as a diagram of a process. He seemed to have extended his views about the modeling process by including repeated observation of the phenomenon under study. This is an enhancement of what he had previously referred to as "plugging away." He also appeared to have a more robust understanding of how models are tested and validated.

After the module, Carl still did not appear to recognize that getting a model to behave like its target is a means for learning how the target behaves. He may have gained respect for the potential of using models to explore what might happen to a system under different conditions, but not the important knowledge that is generated in building models. Carl also appeared to understand modeling in the context of readily observable phenomena such as pond ecosystems and weather, but not in contexts in which the phenomenon is inaccessible, such as geologic events in the distant past.

**5.2.2 Jane**

A comparison of the ratings of Jane's pre- and post-module modeling understandings can be seen in Table 5.2.

**Table 5.2**
*Ratings of Jane's Pre/Post Modeling Understandings*

| | pre-module understandings | | | | post-module understandings | | | |
|---|---|---|---|---|---|---|---|---|
| **DIMENSION** | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| **PURPOSE OF MODELS** | | √ | | | | | √ | |
| **BUILDING MODELS** | √ | | | | | √ | | |
| **CHANGING A MODEL** | | √ | | | | | √ | |
| **MULTIPLE MODELS FOR THE SAME THING** | | √ | | | | | √ | |
| **VALIDATING MODELS** | √ | | | | | √ | | |

**<u>Jane's Pre-Module View of the Purpose of Models (rating: 2)</u>**

Prior to the outset of the module, Jane's view of the purpose of models was rated as pre-scientific. Jane did not recognize a model as a tool used in the generation of new knowledge. Rather, she viewed a model as an aid used to help explain, teach, or present a difficult or abstract concept:

> . . . a scientific model is a tool used to help or explain or describe an idea or concept in science on a smaller, simpler scale than real life concepts. Models are used to help difficult or unclear ideas seem more concrete. (Jane, pre-questionnaire)

While the view of a model as something used for presenting was her primary view of its purpose, she did attribute some other functions to models, albeit in a cursory fashion. Jane mentioned using models for making predictions, using the example of weather models:

> M (Interviewer): About . . . do, do you think they might, that they use models for any, any other reason other than for explaining it to, to someone else?
> J (Jane): You might be able to use it to make predictions about other things.
> M: How, how might you do that?
> J: Weather models. They use weather models all the time and they use those to make weather forecasts and stuff. (Jane, pre-interview, 3/28/02, line181)

She also indicated that models (especially computer models) could be used in place of an actual entity. She cited the example of virtual dissections. Jane also referred to the Ideal Gas Law as an example of a model. She knew that ideal gases do not behave like real gases, but failed to understand that awareness of those differences might yield information about real gases:

> J: Certain things like in chemistry or physics like laws and rules and equations and things like that, they're kind of like models because they're, they're getting to show you like how certain things are supposed to react with other things.
> M: Okay. That's almost like predicting.
> J: Yeah, but I'm sure there's a lot of things in the real world that real scientists like in chemistry labs come across that don't really follow like the ideal gas law or something like that. But I guess that would kind of be considered a model.
> M: You mean the ideal gas law?
> J: Yeah something like that. Or there's a bunch of different, yeah, laws like that that you learn in classes but when you go to the real world, they're kind of not really followed or something. (Jane, pre-interview, 3/28/02, line111)

The view of a model as being used primarily for presenting information is itself a limited view, but Jane also attributed some more scientific purposes to models. Therefore, her view of the purpose of models was rated as pre-scientific.

**Jane's Post-Module View of the Purpose of Models (rating: 3)**

After the module, Jane's view of the purpose of models was rated as emerging-scientific. Jane expressed two distinctive purposes for using models. First, she likened models to concept maps (not literally but implied) where a complex system would become more understandable:

> Because whenever you make the model and you make one, one thing affect another thing and then whenever you have a whole web of relationships, it makes it easier to see how just because something's not directly related how it all related. (Jane, post-interview, 5/2/02, line 45)

The "build" mode of Model-It looks very much like what most people associate with a concept map. The second function of models that Jane described was in order to "test a hypothesis," which she revealed meant to explore what might happen to a system being modeled under different conditions:

> If you, if you think from observing something or from learning about something that something reacts a certain way, you can go to a model and change variables or change . . . or just run a model and see what really happens, what your model shows what happens. (Jane, post-interview, 5/2/02, line 55)

She added that computer models would save time when exploring complex systems:

> . . . if you would go out and actually observe populations and species, it would, you would have to do it over a long period of time like over generations. And if you have data that someone did observe for a while and you can put it into a computer and let it run for generations that would be, it would save you a lot of time. And it would be cost effective and . . . 'cause otherwise it would just take too long to observe that kind of thing. (Jane, post-interview, 5/2/02, line 134)

Jane's view of the purpose of models was rated as emerging-scientific since she referred to using models in place of the actual phenomenon in order to learn how the actual phenomenon would behave under certain circumstances.

**Jane's Pre-Module View of Building Models (rating: 1)**

Prior to the outset of the module, Jane's view of building models was rated as limited. Jane was unable to articulate a process for building models. The primary rationale for designing models that she said was to make sure that the level of detail in the model was appropriate (not too much detail) for the students for whom it was intended. According to Jane, the more information a person wishes to impart, the more detail they should include in their model.

> If you just want everyone to understand that a cell is made up of different things, then it doesn't really have to be that close. But the more intricate or the more the better you want someone to understand something, the more detailed, the more the model is going to have to resemble actual things. (Jane, pre-interview, 3/28/02, line 101)

When considering making a computer model of a cell, the modeler would need to know everything, Jane indicated :

> J: I don't know that a computer would be able to show that like in minute detail.
> M: Okay. What do you have to know?
> J: You have to know like everything. (Jane, pre-interview, 3/28/02, line 148)

Jane's view of building models was rated as limited since she made no connection between the behavior of the model and the behavior of the target.

**Jane's Post-Module View of Building Models (rating: 2)**

After the module, Jane's view of building models was rated as pre- scientific. Jane did not articulate a process for building models per se, but did indicate that data resulting from numerous observations of the target phenomenon would go into the model (see previous quote regarding post-module understanding of the purpose of models). She added that when building models, the modeler must consider relationships:

> To make a model, scientists need to consider all the relationships that exist between all the variables that affect whatever it is they are building the model of. Depending on what purpose their model is serving, they may or may not need to include all these variables. (Jane, post-questionnaire)

Jane indicated that she was uncomfortable building models at times because of having to include relationships about which she was unsure. She even indicated that her pair decided not to include relationships of which they were unsure:

> That's what I didn't really like about building the model because there, there were like a lot of things that I wasn't sure of. Like I knew that sunlight would increase photosynthesis, but I didn't know like what kind of relationship that would be. And just kind of had to guess and that doesn't seem like a very good idea to make a good model. (Jane, post-interview, 5/2/02, line 188)

In addition to these considerations, Jane suggested that one must consider the purpose, and who will be using or viewing a model when it is being built. She explained that the level of detail in the model would influence its results and that scientists probably include more detail in models for their own use than they would when the models were being shown to the general public. She did, however, suggest that their approach to model building would not be any different:

> It would just be a difference in the way that they would present it, if at all. But they would still probably build it the same. (Jane, post-interview, 5/2/02, line 218)

Jane's view of building models was rated as pre-scientific since she did make a connection between empirical data with respect to the target and the model. She did not discuss the iterative nature of modeling, nor has she abandoned the view that an intended audience determines how a model is built.

**Jane's Pre-Module View of Changing Models (rating: 2)**

Prior to the outset of the module, Jane's view of changing models was rated as pre-scientific. Jane indicated that scientists change models when new discoveries are made about the target, or when a scientist changes their mind about some aspect of the model. Similar to her view about building models, Jane saw them as final form entities that get changed as scientists learn more about the target. Jane used the example of scientists studying proteins:

> If they learn that a certain protein does something else, or if their model is that detailed, then they would have to change it because it affects everything else. (Jane, pre-interview, 3/28/02, line 130)

She did not acknowledge the source or process responsible for the new information. Jane does not appear to recognize the role of a model in the generation of that new information.

Jane's view of changing models was rated as pre-scientific because, although she recognized that models could change, she did not acknowledge that they are changed when they are not in agreement with observations of the target.

**Jane's Post-Module View of Changing Models (rating: 3)**

After the module, Jane's view of changing models was rated as emerging-scientific. Jane indicated that models are changed when the behavior of the model is not the same as what is observed of the target phenomenon. She used the example of returning from the second pond during the module and making changes in it when what they observed at the second pond did not agree with what they had predicted with their pond model:

> When we visited the first pond, then built models to show the relationships that we thought existed, we all came back and changed our models based on the new information we observed at the second pond. (Jane, post-questionnaire)

Jane's view of changing models was rated as emerging-scientific since she acknowledged that models are changed based on observations of the target phenomenon. Jane is not explicit about comparing the behavior of the model and target though, which prevents her views from being rated as scientific.

**Jane's Pre-Module View of Multiple Models for the Same Thing (rating: 2)**

Prior to the outset of the module, Jane's view of multiple models was rated as pre-scientific. Jane expressed numerous reasons why there might be multiple models for the same phenomenon. Some aspects of her view of this dimension were more scientific than others. In line with her primary view of the purpose of models as instructional aids, Jane suggested that different models could result from representing the same thing in different ways (such as diagrams and computer-generated models of cells). In addition, she suggested that different models might be designed for different audiences and thus contain different levels of detail (e.g., for high school students or scientists). Expressing a more sophisticated view, Jane also suggested that different models for the same phenomenon might arise due to different theories:

> If there are different theories to a concept, there will certainly be different models. (Jane, pre-questionnaire)

Jane also indicated that different models might be the result of different points of view, or from focusing on different aspects of the same phenomenon. Still, her underlying view is one of using a model for instruction:

> M: Can you think of any reasons why two scientists might end up building a model that's different?
> J: Different points of view that a scientist could have.
> M: Okay. Based . . . .
> J: Related to different outcomes. If one was trying to show one thing about it and the other was trying to show some other aspect of it, they might be different because they'd be focusing on different things.
> M: Okay. You mean . . .
> J: They would have to have like some of the details would have to be the same.
> M: Sure. They'd both have to have a nucleus.
> J: Yeah.
> M: Things like that. So in order to . . . who would they be showing that? I mean you said to show different things.
> J: If one was, if one was trying to teach a class about, like a high school class about something it would be different for one. Trying to teach a group of scientists something. (Jane, pre-interview, 3/28/02, line 166)

Jane's view of multiple models for the same thing was rated as pre-scientific since she expressed some scientific aspects of multiple models, such as focusing on different aspects and different points of view, in addition to aspects considered to be more naïve, such as different levels of detail and audience considerations.

**Jane's Post-Module View of Multiple Models for the Same Thing (rating: 3)**

After the module, Jane's view of multiple models was rated as emerging-scientific. Jane referred to our experiences of building models in class and used the many different pond models that were built as evidence that multiple models can exist for the same phenomenon. When asked to explain this, she emphasized different variables and relationships. She assumed erroneously that most of the groups had the same relationships but varying numbers of variables:

> . . . everyone's model basically included the same relationships, but I guess because some people had like a ton of variables and some people had only a few, that I would consider them different models. (Jane, post-interview, 5/2/02, line 343)

She did not immediately equate different variables and relationships with the modeler's ideas about how the system behaves, but did eventually come to this realization:

> . . . wait a minute. Because I was, I was, I was thinking that it would show that they had what they, the things that they thought they knew were right, but that would just show that they thought the same thing. So that would be not . . . that wouldn't do very much. (Jane, post-interview, 5/2/02, line 372)

Jane's view of multiple models for the same thing was rated as emerging-scientific. She suggested that models are different because of the modelers' different ideas, which result in their building different relationships into their models.

**Jane's Pre-Module View of Validating Models (rating: 1)**

Prior to the outset of the module, Jane's view of validating models was rated as limited. Jane had very little to say about how models are validated or tested. She explained in a very general way her view of the procession of the validation of scientific explanations. She did so when considering how scientists generate knowledge about events that have happened in the distant past. In essence, Jane suggested that many observations are made, followed by speculation about what occurred, but that these speculations are not invalid until nature reveals more (more is discovered about nature):

> M: How do you think, how do you think scientists study things or learn about things that they can't get to and that they can't see? I mean like the formation of the earth or the big bang or things like you know, oh, I don't know, things . . . subatomic particles and things of that nature.
>
> J: I think they do a lot of observations of what they can see and just like the, with the formation of the earth they look at all the rocks and everything that they do have and just make predictions about what they speculate happened. And no one can really prove them wrong until they come up with something else, you know.

Jane's view of validating models was rated as limited since she made no references to comparing the behavior of the model to observations of the real world.

**Jane's Post-Module View of Validating Models (rating: 2)**

After the module, Jane's view of validating models was rated as pre- scientific. Jane indicated that she would trust a model if it made accurate predictions a high percentage of the time. This implied that those predictions were being compared to the behavior of the actual target:

> I don't know that you can 100% trust what a model predicts. But I guess if it, if it makes predictions, other predictions, and you find that those turn out to be true, I guess the hypothesis that you test . . .would be more valid. (Jane, post-interview, 5/2, line 60)

Jane also suggested that a model's validity was based on the relationships contained therein being the result of numerous observations of the behavior of the target phenomenon and the expertise of the modeler:

> . . . before you build a model to make it have that relationship, someone had to observe it and think that that relationship occurred and that it existed. So I guess you just have to trust that the person doing all the model building had enough expertise in that area. (Jane, post-interview, 5/2, line 89)

Jane also commented on testing a model and the implications of predictions that agree with observations and those that do not. She explained that she would be no more likely to reject a model if it *was not* in agreement with observation than she would be to accept a model if it *was* in agreement with observation. Part of her view is shaped by repeatedly correct predictions:

> M: Right. Well, I mean I guess what I'm saying is my model predicts one thing and I go out and observe it and then that's not the case.
> J: And it's different. I don't think that would be a reason to dismiss the relationship either as much as observing it would be a reason to accept it.
> M: Okay. So you're saying if the model predicts incorrectly that the relationships might actually be okay . . .
> J: Yeah.
> M: But if the model, if the model predicts correctly you feel . . . .
> J: I guess if you observe 3,000 ponds and it was . . . and all 3,000 was opposite of what your model predicted, you probably should change the relationships.
> M: Okay. Okay. So if the evidence is overwhelming in other words . . .
> J: I mean I wouldn't be quick to . . . yeah I wouldn't be quick to . . . .
> M: Okay. But if the evidence is overwhelming in other words . . . .
> J: Right.
> M: Okay. But suppose your model predicts correctly 3,000 times?
> J: Then, again I would say that you're probably safe with the relationship that you've built into it. (Jane, post-interview, 5/2, line 457)

She added that it might be useful to "see what others got too (line 475)," meaning to compare the results to the results of other modelers.

Jane's view of validating models was rated as pre-scientific because, even though she suggested that a comparison between the predictions of the model and the target was necessary, she also indicated that some external authority could help to validate a model. She also appeared to weigh agreement with observations and disagreement equally with observations. Generally, she believed that disagreement between prediction and observation is more of a reason to abandon a line of reasoning than agreement in observation is for retaining it.

**Discussion about Jane's Modeling Understandings**

Jane's understandings about scientific models and modeling became more scientific across each dimension. Prior to the module, Jane viewed the purpose of models as being instructional aids. This view of the purpose of models clearly influenced her views of the other dimensions. For example, she based decisions on building models on making sure they would be developmentally appropriate for their audience, be changed when new information is discovered, and come in multiple forms such as diagrams or computer generated graphics. Her view was of a final form entity.

After the module, Jane appeared to recognize that someone attempting to understand a phenomenon versus someone trying to help someone else could use models. She referred to making predictions with models versus merely using models as aids to explanations. Jane also demonstrated a more scientific view by recognizing the importance of relationships among variables in a model in regard to building models and multiple models. After the module, she recognized that changing models is in some way prompted by observations of the target versus her pre-module view that "new discoveries" change models.

Jane's views were not scientific, even though they were more scientific than they had been prior to the module. It was evident that she held the belief that relationships ought to be known by the modeler before they build the model. This would allow him or her to explore what might happen to the system under various conditions. This is one aspect of modeling. However, Jane failed to recognize that getting a model to behave like its target is a means for learning how the target behaves. Jane indicated that she learned a lot about pond ecosystems by building the computer model but did not imagine that scientists could generate knowledge about less well-understood phenomenon in the same way. Jane was frustrated by having to build a model that included relationships of which she was unsure. She failed to realize that this could be a means for her to figure out what those relationships might be.

### 5.2.3 Matt

A comparison of the ratings of Matt's pre- and post-module modeling understandings can be seen in Table 5.3.

**Table 5.3**
*Ratings of Matt's Pre/Post Modeling Understandings*

| | pre-module understandings | | | | post-module understandings | | | |
|---|---|---|---|---|---|---|---|---|
| **DIMENSION** | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| **PURPOSE OF MODELS** | √ | | | | | | √ | |
| **BUILDING MODELS** | √ | | | | | | √ | |
| **CHANGING A MODEL** | | √ | | | | | | √ |
| **MULTIPLE MODELS FOR THE SAME THING** | √ | | | | | | √ | |
| **VALIDATING MODELS** | | √ | | | | | √ | |

**Matt's Pre-Module View of the Purpose of Models (rating: 1)**

Prior to the outset of the module, Matt's view of the purpose of models was rated as limited. Matt did not recognize a model as a tool used in the generation of new knowledge. Rather, he viewed a model as a physical representation used to help someone (presumably a student) understand a difficult or abstract concept, or a concept of some phenomenon that was especially large or small:

> For instance, if I was in an astronomy class and wanted to teach kids about the relationship of the planets I couldn't really bring that into the classroom. So we would represent that in a model. And that would be, could be anything. It could be an orange representing the sun and a grain of salt representing the earth, or a pea. But you would obviously need to explain that that's possibly not the right scale, you know, if you, if you were just . . . it depends on what purpose you were trying to get across. (Matt, pre-interview, 3/28/02, line 26)

Matt could not offer any uses of models for scientists on his own beyond those just described. Matt was then presented with some examples of models in science with which most science students are familiar (e.g., various models of the atom). Based on these prompts, he did suggest that models could serve as "hypothetical representations" that would help scientists develop tests for their theories:

> But obviously you have to sometimes construct some type of a model of hypothetical concepts so that you can at least go down the path and, and do tests that try to support your theory or your hypothesis on that. (Matt, pre-interview, 3/28/02, line 140)

He also suggested, with regard to a different prompt, that scientists could study certain aspects of nature using miniature versions of the actual phenomenon. He was unable to elaborate on either of these notions, though, and could not provide any examples of his own.

Matt's view of the purpose of models was rated as limited since his primary view of them was as physical visual aids for making explanations.

**Matt's Post-Module View of the Purpose of Models (rating: 3)**

After the module, Matt's view of the purpose of models was rated as emerging-scientific. Matt still did not recognize all facets of models as tools used in the generation of new knowledge. He did, however, express the view that models were representations of objects you can't always explain by observing in nature:

> A scientific model is a device that allows someone to explore a natural phenomena or abstract concept, which cannot be easily observed in nature. (Matt, post-questionnaire)

Matt made connections between a modeler's ideas and the model:

> I assume that they speculate on this and create a model that somewhat depicts what they imagine it to look like in three dimensional and then

> they can see the active site and see how you know enzyme substrate reactions occur and better understand, you know, maybe be able to manipulate that and make it . . . I don't know how you'd manipulate it. (Matt, post-interview, 5/1/02, line 124)

Matt suggested that ideas could be tested out on a model prior to testing them "for real" but could not offer any reason why the use of the model was necessary in that case:

> M (Interviewer): So why not just do that . . . why use the model then?
> MA (Matt): Good point. I don't know. Obviously if you could somehow through the model try to see if you could prevent the binding maybe I don't know. I don't know. That's a good question. (Matt, post-interview, 5/1/02, line 140)

He envisioned scientists manipulating some aspect of the model to see what might happen, but the only reason he provided for using a model instead of directly studying the target was in situations where scientists needed to save time or money:

> You know I, I think I viewed scientific modeling more as a teaching tool at the beginning of this. And now I more clearly see that you know how else can science . . . .you know, when, when, when set back by funding and grant money, you know, you, you only have so much research you can do sometimes in the field. You know space exploration is the prime example where you know you're held back because you can't afford to set out on these projects. So what better way than to create models to represent your ideas? (Matt, post-interview, 5/1/02, line 485)

Matt's view of the purpose of models was rated as emerging-scientific since he viewed them as a means for representing one's ideas and using them in place of their targets. His views were not scientific though because he failed to recognize that some phenomena cannot be studied or observed directly. He used the example of space exploration, but it is not really money that limits our ability to explore deep space more directly.

**Matt's Pre-Module View of Building Models (rating: 1)**

Prior to the outset of the module, Matt's view of building models was rated as limited. He suggested that the most important consideration when building a model is to consider what it is that a person is trying to teach. Aspects of the phenomenon being modeled, such as scale, would have to be considered in regard to whether or not they were important in teaching the concept. He was unable to describe any process for building models and did not make any mention of trying to get the model to behave like the target. Matt's view of building models was rated as limited for these reasons.

**Matt's Post-Module View of Building Models (rating: 3)**

After the module, Matt's view of building models was rated as emerging-scientific. Matt was able to clearly describe a process for building models. His description included building a model based on how one perceives a system to behave, making predictions, comparing the predictions of the model to the actual behavior of the target phenomenon, and then making revisions if the predictions of the model and the observations of the target are not in agreement. He clearly recognized that this would be an iterative process:

> You know, you, you make observations, you formulate a hypothesis for the reasons that things are like they are, you come back, you manipulate you create a model that hopefully supports your hypotheses. You test it. If it doesn't match what you saw, then you go out again and, and back that up by looking at another system, a similar system, or a system that is, has a variable different that you were originally at a problem. And you take that data and bring it back, apply it, change and improve or, you know, alter your original ideas or keep them the same if it's, you know, maybe put a couple new variables in that, that weren't present in the other. And that's exactly I'm sure how scientists would carry out scientific research, you know. (Matt, post-interview, 5/1/02, line 467)

Matt's view of building models was rated as emerging-scientific. His views were really scientific, except that he did not appear to understand what could be learned about a system by getting a model to behave like it.

**Matt's Pre-Module View of Changing Models (rating: 2)**

Prior to the outset of the module, Matt's view of changing models was rated as pre-scientific. He indicated that scientists change models when new information comes along. Matt appeared to view models as entities that are changed after scientists learn more about the phenomenon being modeled. Matt suggested that the accepted model for the structure of the DNA molecule might change if scientists developed a super-microscope that would permit them to actually see the structure:

> But as far as developing new technologies I just imagine that someday we probably can find something that's going to get better resolution and maybe we'll be able to look at a DNA molecule. (Matt, post-interview, 5/1/02, line 246)

Matt's view of changing models was rated as pre-scientific because, although he readily acknowledged that models are subject to change, he failed to acknowledge the connection between the behavior of a model and the behavior of the target.

**Matt's Post-Module View of Changing Models (rating: 4)**

After the module, Matt's view of changing models was rated as scientific. He explained quite clearly that models have to be changed if their predictions are not in agreement with observations of the actual target phenomenon (see quote from line 467 of the post-interview above). To Matt, the willingness of a scientist to change his/her explanation of a phenomenon is a critical component of the nature of science:

> You have to observe and collect data that we see and when you make a model, I think it's, it's more designed that what your hypotheses were to begin with. And those are the variables you chose to use. And if you aren't willing to change that, then you know you're not following what the nature of science would be. (Matt, post-interview, 5/1/02, line 331)

Matt's view of changing models was rated as scientific since he clearly recognized that models are temporary and must be changed when the behavior of the model is not in agreement with observations of the target.

**Matt's Pre-Module View of Multiple Models for the Same Thing (rating: 1)**

Prior to the outset of the module, Matt's view of multiple models was rated as limited. Matt suggested that the different models for the same phenomenon would be used for different learning objectives. He explained that a cell could be made out of plastic or modeled with Jello or food. He added that an ideal model would look exactly like its target. Matt's view of multiple models for the same thing was rated as limited since he did not acknowledge any connection between models and the ideas of the modeler in this regard.

**Matt's Post-Module View of Multiple Models for the Same Thing (rating: 3)**

After the module, Matt's view of multiple models was rated as emerging-scientific. Matt initially expressed an educational view of multiple models in the post-module interview when asked about this dimension. He suggested different forms of the same phenomenon (e.g., physical or computer). When questioned further, Matt made an immediate connection between multiple models and competing theories for unexplained phenomena such as dinosaur extinction:

> Well I was, I was confusing the question actually because the question says, Is there, is there a way that someone would use two different, two different representations of the same concept is the question. Whereas where I started to go was there's two different theories. So obviously there would be two different models. (Matt, post-interview, 5/1/02, line 370)

Matt's view of multiple models for the same thing was rated as emerging-scientific since he recognized that different models for the same phenomenon can be related to different explanations or theories about that phenomenon.

**Matt's Pre-Module View of Validating Models (rating: 1)**

Prior to the outset of the module, Matt's view of validating models was rated as limited. He described a physical model of a stream (called a stream table), often found in schools. He indicated that the flow of the water and sedimentation could be modeled with such a system. Matt suggested that if the behavior of this model was similar to the behavior of an actual stream that it would not be very meaningful. Instead, he suggested that a larger scale model of a stream should be built in order to "test" the ideas of the smaller stream table model:

> Oh, just that it would support more of your hypothesis if you're saying it's of a big natural phenomenon, and we're just doing a little terrarium, obviously that doesn't' convince a lot. So if it worked out good on that small scale, then maybe try to up the scale a little more to see if it's still consistent. (Matt, post-interview, 5/1/02, line 378)

Matt's view of validating models was rated as pre-scientific since he did acknowledge, albeit implicitly, a comparison between the behavior of the target and the behavior of the model.

**Matt's Post-Module View of Validating Models (rating: 3)**

After the module, Matt's view of validating models was rated as emerging-scientific. Matt expressed concerns about the validity of modeling as a scientific practice when questioned about how a model is validated. He clearly expressed the necessity of comparing the behavior of the model to the behavior of the target. His concern appeared to be based on the fact that the model behaves as it does because the modeler designs it to behave a certain way. As a result, the model only serves to support the modeler's ideas. Matt viewed this as the downfall of modeling:

> Again, that's a tough one to really consider anything credible whenever you're manipulating variables that support your theories. I mean I don't know if that's helpful at all except to say that yeah I'm right and you're wrong obviously. Look at my model. But you created your model. You, you've made it, you made it the way you wanted to make it. (Matt, post-interview, 5/1/02, line 380)

Matt appeared unable to understand the possibility that getting a model to behave just like an actual phenomenon might provide insight into hidden aspects of how the target actually works. It was as if he could not be convinced about the behavior of a phenomenon unless it could be directly observed.

Matt's view of validating models was rated as emerging-scientific. His views were actually scientific, but he failed to recognize modeling as a legitimate means for generating understanding about an unexplained inaccessible phenomenon.

## Discussion about Matt's Modeling Understandings

Matt's understandings of scientific models and modeling became more scientific across each dimension, significantly so in certain dimensions. Prior to the module, Matt only expressed an instructional aid view as being the purpose of models. In this view, models would be used to help students learn about difficult or inaccessible phenomenon. He even went so far as to suggest that showing a scale was modeling. Matt's view of the purpose of models was apparent when discussing many of the dimensions of models and modeling, however. For example, he suggested that considerations for building models be based on what was being taught and that different models for the same phenomenon might reflect different learning objectives. Prior to the module, Matt viewed models as final form entities that get changed as new technologies force nature to reveal more.

After the module, Matt could clearly articulate how models are built and tested. In an interesting turn of events, he actually demonstrated how he had translated his modeling understandings for classroom use. He did some explicit instruction on modeling in his pre-student teaching field experience. Matt had explained to his students that models are used to clarify a concept that we can't really go out and explore because of time. Matt even went so far as to include a test question on modeling in which he asked students to explain the downfall of modeling. The answer he sought was that models involve assumptions and that all variables cannot be accounted for.

Although many of his understandings of the purpose for models were enhanced, Matt did not recognize modeling as a legitimate means for generating knowledge about a phenomenon. To Matt, models merely represent the modeler's ideas. He failed to understand that capturing one's ideas about the behavior of a phenomenon in a model and comparing that to the behavior of the phenomenon might provide insights as to whether or not those ideas were plausible. He did not recognize that, in many cases, modeling is the only means for making such comparisons. He instead focused on the limitations of models rather than on their potential.

### 5.2.4 Kate

A comparison of the ratings of Kate's pre- and post-module modeling understandings can be seen in Table 5.4.

**Table 5.4**
*Ratings of Kate's Pre/Post Modeling Understandings*

| | pre-module understandings | | | | post-module understandings | | | |
|---|---|---|---|---|---|---|---|---|
| **DIMENSION** | **1** | **2** | **3** | **4** | **1** | **2** | **3** | **4** |
| **PURPOSE OF MODELS** | | | √ | | | | | √ |
| **BUILDING MODELS** | | | √ | | | | √ | |
| **CHANGING A MODEL** | | | | √ | | | | √ |
| **MULTIPLE MODELS FOR THE SAME THING** | | | | √ | | | √ | |
| **VALIDATING MODELS** | | | | √ | | | | √ |

**<u>Kate's Pre-Module View of the Purpose of Models (rating: 3)</u>**

Prior to the outset of the module, Kate's view of the purpose of models was rated as emerging-scientific. Kate suggested that models could be used to make predictions about phenomenon that are difficult study.

> Well, like with nuclear bombs. We don't want to, you know, just blow them up and see what happens. And like with global warming too big of a situation, you can't predict the future. Like models can be used to predict what's going to happen. (Kate, pre-interview, 4/1/02, line 34)

Kate discussed computer models at length and explained that computers would be needed to build models of complex phenomena due to their capacity for handling complex mathematical calculations. Kate also indicated that models were important because they are being used to influence policy:

> One of the most important models currently being used is the meteorology model used to predict global warming and its effects on different factors, such as average temperatures, and precipitation. These are being used to guide environmental and economic policy. (Kate – pre-questionnaire)

Kate's view of the purpose of models was rated as emerging-scientific since she recognized that a model is a tool used in the generation of knowledge about a phenomenon.

**Kate's Post-Module View of the Purpose of Models (rating: 4)**

After the module, Kate's view of the purpose of models was rated as scientific. Kate again suggested that models could be used to make predictions about phenomena that are not easily tested. She used the examples of events in the past or situations where making changes to aspects of the actual phenomena would cause irreversible or unfixable effects. Kate elaborated on using a model to determine what carbon dioxide levels may have been like on earth millions of years ago:

K (Kate): Kind of work it backwards to see what . . .
M (Interviewer): So, okay, so I build a, I build a model, a global climate model, and then I set the conditions to what I think they were and a long time ago?
K: Yeah.
M: And then run my model and then what?
K: And then it would show you what the climate would be like with those conditions.
M: Okay.
K: If those conditions were true that's what the climate would be like.
M: So what, what would I learn by doing that?
K: Just different possible climates for the past. Like you could either maybe find the $CO_2$ levels that way by if you know that the climate was warm, see what $CO_2$ levels are necessary to make the climate work, like if you do it backwards. (Kate, post-interview, 4/30/02, line 94)

Kate's view of the purpose of models was rated as scientific since she indicated that models could be used in order to generate information about their target. She extended her view to include using models to understand past events as well as to predict future events.

**Kate's Pre-Module View of Building Models (rating: 3)**

Prior to the outset of the module, Kate's view of building models was rated as emerging-scientific. Kate acknowledged that the process of building a model would include identifying what it is you are trying to figure out and then designing a model to predict the behavior of that target phenomenon as closely as possible. She added that the more similar the behavior the better the model:

K: Yeah. It has to be, it has to act, it doesn't have to look the same way. It has to behave the same way.
M: Okay.

K: As, I mean, the more similar it behaves the more, better model it could be. (Kate, pre-interview, 4/1/02, line 165)

Kate indicated that the modeler must keep in mind all the potential variables related to the target when building a model. She also suggested that variables that did not have a direct bearing on the problem at hand could be excluded from a model. Kate discussed computer models and mentioned that they would always be a little too perfect because they could not account for the random behavior of organisms in ecosystems since computers can only behave as they are programmed to behave.

Kate's view of building models was rated as emerging-scientific instead of scientific because although she made a clear connection between the behavior of the model and the target, she did not acknowledge the iterative nature of modeling.

**Kate's Post-Module View of Building Models (rating: 3)**

After the module, Kate's view of building models was rated as emerging-scientific. Kate again acknowledged that the process of building a model would be undertaken for the express purpose of getting it to behave the same way as the target. She indicated that the variables and relationships used in the model would be tailored to focus on the question that the modeler was trying to answer. She added that not all variables could be included and that the relationships should be chosen based on those that can be observed:

> You must think about what relationships you want to show and what you want the output to show and then design your model so that it predicts things that you know it should predict. (Kate, post-questionnaire)

M: You said you must think about what relationships that you want to show. Why would you want to show relationships? Or to whom would you want to show relationships?

K: I think there are spaces for things you know prioritize like if there's one variable you're looking at basically like $CO_2$ levels or temperature, then stick to that variable and don't try and find all, you know, you can't model the system exactly I don't think. There are too many variables that we can't, we can't know. (Kate, post-interview, 4/30/02, line 136)

Kate's view of building models was rated as emerging-scientific instead of scientific because, although she made a clear connection between the behavior of the model and target, she did not acknowledge the iterative nature of modeling.

**Kate's Pre-Module View of Changing Models (rating: 4)**

Prior to the outset of the module, Kate's view of changing models was rated as scientific. Kate suggested that a model could be changed if it does not behave like the target:

> A scientist could change a model whenever it was found that something was missing or not behaving as it was supposed to. (Kate, post-interview)

Kate's view of changing models was rated as scientific.

**Kate's Post-Module View of Changing Models (rating: 4)**

After the module, Kate's view of the purpose of models was rated as scientific. She again suggested that a model could be changed if it does not behave like the target. She added that changing a model would include changing or adjusting relationships among variables in the model:

> If a scientist were to design a model and then test the model and not get the expected results, a scientist can and should tweak the model, change the relationships so that it is more effective. (Kate, post-interview)

Kate's view of changing models was rated as scientific.

**<u>Kate's Pre-Module View of Multiple Models for the Same Thing (rating: 4)</u>**

Prior to the outset of the module, Kate's view of multiple models was rated as scientific. Kate suggested that different models for the same phenomenon might be used in order to focus on different aspects of the phenomenon. She imagined breaking a complex phenomenon down into smaller parts in order to focus on individual aspects of the phenomenon. She added that, in some cases, different models for different aspects of a target might yield different predictions that could be useful in the case of predicting the behavior of a complex phenomenon:

> If we stick with the global warming thing, you could model precipitation with one model and temperature with one model and you know that kind of thing. I don't know I think you know wind speed with one model. Like it might be too complex to do the models with one or . . . I guess also you don't always know what model is going to work out the best. So if you do a couple different models you can get, well, it's either going to behave like this or like this. (Kate, pre-interview, 4/1/02, line 232)

Kate indicated that different models for the same phenomenon would result from the inclusion of different variables, and in cases where variables were related in different ways:

> M: What, what are some of the things that would make those two choices different?
>
> K: Different ways of like different variables that you put in different ways the variables are used with each other.
>
> M: Okay.

> K: Different ways that they relate you can . . . maybe also have two different models to describe slightly different situations. (Kate, pre-interview, 4/1/02, line 244)

Kate's view of multiple models for the same thing was rated as scientific since she recognized that different aspects of a phenomenon could be the focus of different models as well as have different assumptions about how the variables in a model are related.

**<u>Kate's Post-Module View of Multiple Models for the Same Thing (rating: 3)</u>**

After the module, Kate's view of multiple models was rated as emerging-scientific. Kate suggested that different models for the same phenomenon would result from different assumptions about the behavior of the target:

> I mean by taking the same . . . you can take the same information and come up to different, draw a different conclusions and stuff. So since both scientists are kind of using I guess their best guess, then their guesses can be different and it can be valid if they're different. It's not a problem. Like it's fine. They're just both using the information they have to make a prediction. (Kate, post-interview, 4/30/02, line 287)

She indicated that different modelers would build different mathematical relationships, which would result in their models behaving differently

Kate's view of multiple models for the same thing was rated as emerging-scientific since, although she recognized that different models result from different assumptions about how the variables in a model are related, she failed to indicate that different models for the same phenomenon might focus on different aspects of the target.

**Kate's Pre-Module View of Validating Models (rating: 4)**

Prior to the outset of the module, Kate's view of validating models was rated as scientific. Kate suggested that making sure that they can predict aspects of the target that are known for certain could validate models.

> And if you can see that the model's not predicting things, you can kind of take . . . I would say you could . . . there's some things you could put into the model that's supposed to show that you do know you know like pick current weather conditions if you're looking at the weather thing and make sure it predicts what we do know. And if it doesn't, then you know you could go back and look to see what might be missing and take other factors and look at them. (Kate, pre-interview, 4/1/02, line 209)

Kate's view of validating models was rated as scientific since she clearly explained that a model is validated via comparison between the behavior of the model and target.

**Kate's Post-Module View of Validating Models (rating: 4)**

After the module, Kate's view of validating models was rated as scientific. Kate again explained that models are validated by comparing the behavior of the model to the behavior of the target phenomenon. She added that in some instances direct observation of the target phenomenon is impossible, and in those cases, the model would have to be able to predict aspects of the target phenomenon that could be observed.

> M: Okay. Is there any way for me to know, is there any other way for me to know whether or not my model is viable? I mean my model predicts that if the $CO_2$ levels were high, then the climate was warm. Is there any other? Do I have any other way of knowing whether or not my model is viable?
> K: You can type in present conditions to see if the present climate is what shows up.
> M: Oh, okay.

K: If you type in the present $CO_2$ level and solar constant and see if what you get is similar to the current climate
M: So, if it's working now then I might be able to extrapolate . . .
K: Yeah. I mean there are sometimes in the past where they can get $CO_2$ levels out of like mud sediment, ice. They can compare you know those climates to that, the little bit of variability and compare different (inaudible). (Kate, post-interview, 4/30/02, line 119)

Kate was able to apply these principles to events that happened millions of years ago as well as to pond ecosystems. It is important to note that Kate voiced some level of distrust of models since the modeler could be unsure (as was she) of certain relationships built into a model. When discussing scientists' use of models, she later admitted that they too would include some of their "best guesses" as to the manner in which certain variables in a model are related.

Kate's view of validating models was rated as scientific since she explained that a model is validated by comparing the behavior of the model and the target.

**Discussion about Kate's Modeling Understandings**

Kate's understandings of scientific models and modeling changed very little. She expressed sophisticated views prior to and after the module. The most noteworthy difference between her pre-module and post-module understandings was her ability to discuss in greater detail how models could be validated and how a model could be used to explain events and conditions that occurred so long ago. Kate's rating for multiple models was lower after the module. The drop in rating is most likely the result of her not mentioning using different models to model different aspects of the same phenomenon, as she had prior to the module, as opposed to her having changed her views on this dimension.

### 5.2.5 Jackie

A comparison of the ratings of Jackie's pre- and post-module modeling understandings can be seen in Table 5.5.

**Table 5.5**
*Ratings of Jackie's Pre/Post Modeling Understandings*

| | pre-module understandings | | | | post-module understandings | | | |
|---|---|---|---|---|---|---|---|---|
| **DIMENSION** | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| **PURPOSE OF MODELS** | | √ | | | | | √ | |
| **BUILDING MODELS** | √ | | | | | √ | | |
| **CHANGING A MODEL** | | √ | | | | | √ | |
| **MULTIPLE MODELS FOR THE SAME THING** | | √ | | | | √ | | |
| **VALIDATING MODELS** | | √ | | | | √ | | |

**<u>Jackie's Pre-Module View of the Purpose of Models (rating: 2)</u>**

Prior to the outset of the module, Jackie's view of the purpose of models was rated as pre-scientific. Jackie held multiple views of the purpose of models in science. The first view she articulated, an educational view, was a step-by-step protocol that one person (presumably a teacher) would explain or demonstrate for someone else who was to follow that protocol:

> J (Jackie): I don't know. It was sort of like experiments, how there are steps like a procedure.
> M (Interviewer): Okay.
> J: Models are . . . that's what I sort of thought of where models were examples of how scientists did things and then it was like step 1

> and then that's what they did. (Jackie, pre-interview, 4/1/02, line 19)

Jackie admitted to not knowing much about models and confessed to having done research about models while completing her pre-module questionnaire. It is possible that some of her responses reflect her own expanding view of models and modeling in science at the time of the interview. Jackie described how scientists might use models that included two different purposes. She made a clear connection between models and ideas. First, she explained that scientists build models and then showed them to other scientists to "see if they're right" or to compare ideas:

> M: Okay. So if I have some idea of what I think a cell looks like or how it's put together or how it functions or something like that and I, I can, I build a model of that. Okay. But what could I do with it?
>
> J: I guess you can show it to other people and try and get like a consensus.
>
> M: Okay. So, I mean I can show them, I can show them what it . . . I can show them, okay this is how, this is what I think. Okay. And then what would I be doing by showing . . . why would I be trying to show them?
>
> J: To see like if you're correct or not in your judgment. (Jackie, pre-interview, 4/1/02, line 165)

As her views were probed, Jackie also suggested that models could be used to test hypotheses and that experiments could be run on them. She alluded to computer simulations that she had used in class just prior to her interview and indicated that scientists might use simulations to see what happens:

> J: I don't know. You can run different experiments. Like the simulations that we did. (Note: We had worked with simulations and microworlds in the class sessions prior to the outset of the modeling module.)
>
> M: Okay.

J: You can run simulations on your model to see what would happen, I guess. (Jackie, pre-interview, 4/1/02, line 216)

Jackie's view of the purpose of models was rated as pre-scientific because, although she initially expressed a view of models as something to show to someone, she appeared to recognize models as tools for generating knowledge at some level, by her comments about scientists using computer simulations to "see what happens."

**Jackie's Post-Module View of the Purpose of Models (rating: 3)**

After the module, Jackie's view of the purpose of models was rated as emerging-scientific. Jackie again expressed the view that models can be used to test ideas. She equates the terms hypothesis and ideas:

> A scientific model is something that scientists can use to test their hypothesis. It is the way they test their ideas if it would be too hard, time consuming, or impossible to test any other way. It can be done on computers or it can be built by hand. (Jackie, post-questionnaire)

Jackie suggested that models could be built on a computer, or physically, but recognized that variables could be changed more easily on a computer model. Jackie was prone to using scientific terms such as test, hypothesis, and theory. When asked to clarify what she meant by "test" a model, it appears that she meant that a model could be used to see what would happen to a system (such as a pond) if certain variables related to the system were changed. Jackie appeared to equate the use of models with the generation of knowledge, but she could not explain exactly how this was accomplished:

J: I don't know. Scientists build things all the time. Like . . . or Space Day. He was testing like the soil moisture in Iowa and I think that they were building using that information and then building things to describe like weather patterns and stuff like that.

M: Okay. So how, how could a model be used to investigate weather patterns?
J: I don't know. I think like it was going to help them predict like what they expected the weather to be like over time.

Jackie's view of the purpose of models was rated as emerging-scientific since she recognized that models are used to generate information about natural phenomenon and acknowledged that models are used when the model is inaccessible for some reason.

**Jackie's Pre-Module View of Building Models (rating: 1)**

Prior to the outset of the module, Jackie's view of building models was rated as limited. She was unable to describe any process for building models. She explained that the modeler must possess basic understanding and knowledge about what is being modeled but described the process of doing so as "finding a way to build it (pre-interview, line 385)." What must be included in a model related to her shows/demonstrates a description of the purpose of models. She suggested that models have to be very close to their targets so that one does not teach the wrong information:

M: How close do you think a scientific model has to be to the thing itself?
J: I think it has to be really close.
M: Why is that?
J: Because if it's not then you're teaching people, you're giving them wrong information. And then that will lead to like a whole bunch of other problems. (Jackie, pre-interview, 4/1/02, line 198)

Jackie's view of building models was rated limited since she could not articulate any process for model building.

**Jackie's Post-Module View of Building Models (rating: 2)**

After the module, Jackie's view of building models was rated as pre-scientific. She acknowledged that building relationships among variables was a component of the process if building models, but was unable to describe a process for doing so beyond that one aspect:

> And then you'd like bring it all together and you'd have to try and make the relationships and the connections again. (Jackie, post-interview, 4/26/02, line 126)

She did, however, refer to the importance of including aspects of the target in the model. Jackie suggested that physical data (such as pH) would need to be included in a pond model and that historical weather data would need to be included in a weather model. She failed to acknowledge, however, that the model had to be designed to behave like the target phenomenon. She used the examples of a model heart and the computer pond models:

> J: Well I think I was thinking about that and then compared to this like how you could do it on the computer and you didn't really need to build the pond.
> M: Oh, okay.
> J: Do you know what I mean?
> M: So you think in some cases you actually have to have something tangible.
> J: Yeah.
> M: Whereas in this, you think you could make a, a model heart with Model-It or a computer program?
> J: Yeah?
> M: Yeah. Okay. So you think if it was something tangible it would need to be exactly like the thing?
> J: Just scaled or whatever. (Jackie, post-interview, 4/26/02, line 333)

Jackie's view of building models was rated as pre-scientific since she made explicit references to include actual aspects of the target in the model.

**Jackie's Pre-Module View of Changing Models (rating: 2)**

Prior to the outset of the module, Jackie's view of changing models was rated as pre-scientific. She indicated that scientists change models when new discoveries are made or more recent information about the target becomes available. She added that the model would be adapted to accommodate the new information:

> Because you might not know something that somebody else had like just found out or is more recent. Then you would sort of adapt it and add in the new information. (Jackie, pre-interview, 4/1/02, line 178)

Jackie made a point to clarify her thoughts on this matter. She explained that she was under the impression that new discoveries, from experiments, would prompt someone to change their model:

> J: I don't know if it's the model that really leads to new ideas, but it's the new idea that leads to new ideas for your model. Do you know what I mean?
>
> M: No. Maybe you could elaborate because I'm not quite sure I understand what you mean.
>
> J: All right. Sort of like if you run an experiment and you find out new information on a certain thing, then that would lead to the new information that you have to change in your model. (Jackie, pre-interview, 4/1/02, line 241)

She did not view the model as an instrument in the discovery but rather something that would be changed after new discoveries were made.

Jackie's view of changing models was rated as pre-scientific because, although she readily acknowledged that models are subject to change, she failed to acknowledge the connection between the behavior of a model and the behavior of the target.

**<u>Jackie's Post-Module View of Changing Models (rating: 3)</u>**

After the module, Jackie's view of changing models was rated as emerging-scientific. Jackie suggested that models change when they do not correctly predict events. She expressed this view in reference to weather models:

> M: All right. Okay. And you said you also have to keep in mind that your model may have to change before you get it absolutely right. So why would a model, why would it need to change?
> J: Well, like if you tested it and it turned out completely wrong.
> M: So, if I was trying to use a weather model to predict what happened yesterday and it said it was supposed to snow . . . .
> J: Yeah. Then something in there isn't right. And so you have to go back in and change something. (Jackie, post-interview, 4/26/02, line 324)

Jackie also suggested that scientists would change their model if information from other scientists demonstrated that their model was incorrect.

> Well, if they'd ever like . . . they thought something was supposed to work the way it did, but then somebody came out with like their new research to prove them wrong, then they have to go back and change it based on . . . or, at least, reconsider based on the new findings. (Jackie, post-interview, 4/26/02, line 368)

Jackie's view of changing models was rated as emerging-scientific since she suggested the failure of a model to behave like its target as a reason for changing a model.

**Jackie's Pre-Module View of Multiple Models for the Same Thing (rating: 2)**

Prior to the outset of the module, Jackie's view of multiple models was rated as pre-scientific. She equated models with ideas in discussing multiple models. She suggested that different people have different ideas and will therefore have different models for things:

> Well, I don't know. Different people have different ideas. So then they can have their different models and then test out their ideas. (Jackie, pre-interview, 4/1/02, line 270)

Jackie's view of multiple models for the same thing was rated as pre-scientific because she was able to explain that different models could represent different ideas about the same entity.

**Jackie's Post-Module View of Multiple Models for the Same Thing (rating: 2)**

After the module, Jackie's view of multiple models was rated as pre-scientific. She offered a variation on her pre-module views on multiple models. Jackie suggested that multiple models could be used for the same phenomenon in order to focus on various aspects of it. When asked to elaborate, she revealed that she felt it would be easier to focus on fewer aspects at once. This view was in reference to using Model-It and only measuring or tracking one or two variables at once. In other words, she did not really envision using separate models but focusing on different variables of the same model. Jackie also expressed the same view she had expressed prior to the module in which different models for the same target reflect different modelers' ideas about the behavior of the model, and when asked to elaborate, she suggested that those different models might contain different relationships:

> I think it would be like because it was based on their different variables in between, like the relationships that they made. (Jackie, post-interview, 4/26/02, line 485)

Jackie's view of multiple models for the same thing was rated as pre-scientific since it had not changed qualitatively even though it appears to be more coherent.

**Jackie's Pre-Module View of Validating Models (rating: 2)**

Prior to the outset of the module, Jackie's view of validating models was rated as pre-scientific. Jackie had little to say about validating or testing models. Initially she suggested that one could never know if a model was working correctly and that a given model might be correct for the time. Later, when considering scientists' use of models, she explained that a scientist could run a computer simulation and then test it by examining the target phenomenon. She added that if the results were not in agreement, the scientists would need to retest or start over:

> J: You can run simulations on your model to see what would happen I guess.
> M: Okay. So if my, if my model, something happens when I, when I do that what's the, you know, let's say my model says that such and such is going to happen if I do this. What does that . . . .
> J: Then you can sort of I guess, go and try it for real to see if that really does happen.
> M: Okay.
> J: And then you can build.
> M: Okay. So, if it doesn't, if it doesn't turn out the way my model says it should, then what?
> J: I don't know. There's something wrong I guess. And you can either retest it or start all over. (Jackie, pre-interview, 4/1/02, line 218)

Jackie's view of validating models was rated as pre-scientific since she did mention, though somewhat vaguely, that there must be some comparison between the model and the actual target phenomenon.

**Jackie's Post-Module View of Validating Models (rating: 2)**

After the module, Jackie's view of validating models was rated as pre-scientific. Jackie spoke in more detail about her views regarding validating models. They were not really qualitatively different, however. She again suggested that the predictions made by models would need to be compared to "what really happens" (post-interview, line 170). She was able to extend this notion to weather predicting by suggesting that if a weather model could correctly predict past weather, it could be trusted to predict future weather. She also offered two other, less scientific indicators for the validity of a model. The first was whether or not the model was behaving as the modeler expected based on his/her experience and previous knowledge:

> J: If it turns out like what they thought it should be . . .
> M: Well, how would they . . . okay. So, let's see. What, what do you think, how do you think they know what it should be?
> J: I don't now. Based on like previous knowledge and experiences.
> M: Okay.
> J: They sort of have a basic idea of what it should look like. (Jackie, post-interview, 4/26/02, line 291)

The second was to check with other scientists or to look up information in books.

> M: Okay. How would we know if they were right?
> J: I don't know. Or you could check like all of those books that really had for like the conditions.
> M: Okay. Suppose I was building a model, a model for I don't know the formation of the earth. That happened you know I don't know billions of years ago.

J: I don't know how you'd know if you were right or not. (Jackie, post-interview, 4/26/02, line 646)

Jackie's view would have been rated as emerging-scientific if she had not referred to an external authority as a means for validating models but instead expressed the view regarding the model's agreement with observations of the target. Therefore, her view of validating models was rated as pre-scientific.

**Discussion about Jackie's Modeling Understandings**

Jackie's understandings about scientific models and modeling became more scientific in 3 out of 5 dimensions. Prior to the module, Jackie made many references to using models primarily to teach, and she occasionally alluded to more scientific purposes such as testing hypotheses. Her views of other dimensions did not necessarily relate to one purpose more than another. For example, she thought models needed to be built in such a way so as not to mislead students. This view clearly relates to an instructional purpose of models. In contrast, she associated different models with different modelers' ideas, suggesting that these ideas could be tested. Jackie did, however, consistently view models prior to the module as final form entities that get changed when new discoveries are made.

After the module, Jackie made fewer references to models being used for teaching. Instead she focused almost exclusively on her own recent experiences of building models and how she perceived that scientists use them. She extended her view of the purpose of models by suggesting that they are used in place of the target when the target is difficult to work with for some reason. Perhaps the most notable change in her views was in her repeated references to comparing the behavior of the model with what happens to the actual target phenomenon.

In some instances, it was as if she solidified the aspects of her views that were more scientific and let go of some of her more limited views. Jackie still does not recognize that the process of getting a model to behave like its target informs the modeler about the behavior of the target. While she acknowledges that getting a model to behave like its target is important in building models, she does not appear to recognize that achieving agreement in the behavior of a model and its target is a means for validating the model.

### 5.2.6 Jean

A comparison of the ratings of Jean's pre- and post-module modeling understandings can be seen in Table 5.6.

**Table 5.6**
*Ratings of Jean's Pre/Post Modeling Understandings*

| | pre-module understandings | | | | post-module understandings | | | |
|---|---|---|---|---|---|---|---|---|
| **DIMENSION** | **1** | **2** | **3** | **4** | **1** | **2** | **3** | **4** |
| **PURPOSE OF MODELS** | | √ | | | | | √ | |
| **BUILDING MODELS** | | √ | | | | | √ | |
| **CHANGING A MODEL** | | √ | | | | | √ | |
| **MULTIPLE MODELS FOR THE SAME THING** | | | √ | | | | √ | |
| **VALIDATING MODELS** | | √ | | | | | √ | |

**<u>Jean's Pre-Module View of the Purpose of Models (rating: 2)</u>**

Prior to the outset of the module, Jean's view of the purpose of models was rated as pre-scientific. She viewed a model primarily as a visual aid for learning about a phenomenon. She expressed the general view that models are *visual aids* when discussing various aspects of models and modeling. The evidence supporting this characterization of her views cut across many of the dimensions of modeling. Jean imagined scientists using models to accompany explanations to lay-people and people of equal knowledge (other scientists):

> J (Jean): And can, and you can use it as a tool to explain.
> M (Interviewer): Right. So you think that that is the primary function of a model, for a scientist to use it to explain something to someone else?
> J: Yeah.
> M: Okay, another scientist or . . . .
> J: Yeah. I think two levels, whether scientist or in their field or just to the public. (Jean, pre-interview, 3/29/02, line 71)

When pressed to consider other uses of models, Jean described a physical entity that could be built to help a scientist visually think about a phenomenon as well as give the scientist something to physically manipulate to explore possibilities:

> Maybe it all just helps organize what they are thinking. They can actually see what they're thinking and can make better ties if it's like a visual instead of a concept in their head. (Jean, pre-interview, 3/29/02, line 29)
>
> They can maybe when they put it into a model, they can see and they do more research, they can see maybe what would work and what wouldn't because it will be 3-D. And like they can either support or negate what they thought before if they've put it to use in a model. (Jean, pre-interview, 3/29/02, line 92)

She also mentioned a computer simulation program that could be manipulated. The program allowed the user to choose the order of a process and see if they did so correctly. Jean did not view the process she experienced while using the program as an activity in which scientists would engage. She was really unable to describe how scientists go about generating knowledge about events that occur without our being able to directly observe them.

Jean's view of the purpose of models is somewhat limited since she suggested that a model is a final form entity that is used by someone who understands the phenomenon in order to explain it to someone else who does not. Still, she was able to imagine models to be useful in some way in the generation of new knowledge and did at some level equate simulations and models. Therefore she was rated as pre-scientific.

**Jean's Post-Module View of the Purpose of Models (rating: 3)**

After the module, Jean's view of the purpose of models was rated as emerging-scientific. She viewed models as tools used by scientists to generate understanding or to make discoveries about a system in which they are interested. It is clear that she viewed models as a means for gaining insight about a phenomenon. She was less clear in expressing her views on how this occurs:

> . . . everything we learned about the fish, the air, everything that goes into the pond we were able to manipulate kind of and relate, and those relationships kind of define what the system is. So being able to manipulate those, you know, gives us a better idea of what the system is capable of. (Jean, post-interview, 4/29/02, line 30)

Jean also indicated that a computer model possessed capabilities that would not be permissible from studying the pond directly. In other words, in situations where manipulating variables associated with the pond would be detrimental to the pond, a computer model could be used in place of the pond.

> . . . just the relationships, just, like you can relate pretty much anything you want on this and you might not be able to do that with a real pond. (Jean, post-interview, 4/29/02, line 40)

Jean's view of the purpose of models was rated as emerging-scientific because she viewed models as tools for generating new knowledge about a target as well as an entity to be used in place of a target. Her view is not scientific because she did not articulate that the process of getting a model to behave like its target is a means for understanding the behavior of the target itself.

**Jean's Pre-Module View of Building Models (rating: 2)**

Prior to the outset of the module, Jean's view of building models was rated as pre-scientific. She did not articulate a process for building models. The views she expressed regarding what would need to be considered while building a model were commensurate with her visual aid conception of the purpose of a model. Jean suggested that models must be accurate in sufficient detail so that the user would understand the concept after using it. She explained that the audience for whom the model was intended would mediate the level of detail. For instance, the level of detail would need to be higher for scientists using the model versus a layperson:

> I think it is. It depends on what audience you're like looking at. Like some, like if there's an audience that isn't of science, they don't, aren't

> very interested in anyway. I think too much detail can be discouraging or overwhelming and make them not even . . . they might just disregard it. (Jean, pre-interview, 3/29/02, line170)
>
> I think it is. It depends on what audience you're like looking at. Like some, like if there's an audience that isn't of science, they don't, aren't very interested in it anyway, I think too much detail can be discouraging or overwhelming and make them not even . . . they might just disregard it. (Jean, pre-interview, 3/29/02, line173)

Jean mentioned using models in research, and when discussing making a mechanical arm, implied that the scientist's ideas are represented in the model:

> M: Okay, so they could, they could manipulate the model?
> J: Yeah.
> M: And then what would that, where would that . . . .
> J: Given what they know what is known, they can make those like the constants. And then maybe learn other things by manipulating the knowns. (Jean, pre-interview, 3/29/02, line104)

Jean's view of the building models was rated as pre-scientific because, although she did not make an explicit connection between building models and observations of nature, she did acknowledge, in passing, that a scientist's ideas go into a model when it is being built.

**<u>Jean's Post-Module View of Building Models (rating: 3)</u>**

After the module, Jean's view of building models was rated as emerging-scientific. Jean did not articulate a modeling process per se, but she clearly expressed the notion that a critical aspect of building a model is to get it to behave like its target:

> I think the characteristics of the real thing must be represented accurately by the model in order for the model to predict good results. The model does not have to look like the real thing, but it needs to have the ability to react in the same way as the real thing. (Jean, post-questionnaire)

Jean continued to make an explicit connection between the modeler's ideas and a model. She also indicated that the Model-It software was different than a simulation she had used because Model-It requires the user to create the relationships among the variables inherent in the phenomenon. She suggested that since modeling is used for the study of complex systems, a model must incorporate many variables.

Jean's view of building models was rated as emerging-scientific primarily due to her recognition that the agreement between the behavior of the model and the target mediates how the model is built. Her view is not quite scientific because she failed to articulate the iterative nature of the modeling process.

**Jean's Pre-Module View of Changing Models (rating: 2)**

Prior to the outset of the module, Jean's view of changing models was rated as pre-scientific. Jean indicated that scientists change models when new information comes along from another source, such as another scientist or scientific discovery. She acknowledged that although it is difficult to change commonly held beliefs, a model could be changed completely:

> Maybe something they didn't think about before or a new . . . if something else from another scientist or another person is discovered or, or thought of, then they can maybe apply it to what they know and it will change everything. It could change everything. (Jean, pre-interview, 3/29/02, line138)

Jean's view of changing models was rated as pre-scientific because, although she readily acknowledged that models are subject to change, she failed to acknowledge the connection between the behavior of a model and the behavior of the target.

**Jean's Post-Module View of Changing Models (rating: 3)**

After the module, Jean's view of changing models was rated as emerging-scientific. She expressed the view that models are changed if they are found to be incorrect or outdated. In explaining the latter, she indicated that new discoveries might prompt changes in a model. Regarding the former, Jean suggested that models could be shown to be correct or incorrect by testing them. She was able to provide an appropriate example based on weather predicting to support this view in which she made an explicit connection between the agreement between the predictions of a model and observations of the target phenomenon:

> J: . . . before you can know that you're right with the relationships that you're making, maybe like days that have already happened. What happened on yesterday and get readings of what the temperature was, what the moisture was, like data from that day when you know what result is. And then make relationships yielding that result and then maybe you can be more accurate knowing that it's working. (Jean, post-interview, 4/29/02, line 424)

> Instr1: So that's what you mean by outdated. How would I know if my model was inaccurate?
>
> J: (Pause) I guess you wouldn't know unless you tested it, like the weather thing. Tested it previously . . . . (Jean, post-interview, 4/29/02, line 476)

Jean's view of changing models was rated as emerging-scientific since she clearly indicated that models are subject to change and made an explicit connection between the behavior of the model and the behavior of the target.

**Jean's Pre-Module View of Multiple Models for the Same Thing (rating: 3)**

Prior to the outset of the module, Jean's view of multiple models was rated as emerging-scientific. She demonstrated fairly sophisticated views regarding multiple models for the same phenomenon. It was here that she made an explicit connection between models and explanations. Jean suggested that different models might be the result of different explanations (she used the term interpretations) for how a process proceeds:

> Well, if it's something that isn't like accepted as truth. Like there could be different interpretations of something or like something in biology like let's say how protein folding happens. Like it's still hard to know how it happens, but there could be different theories on how it happens. And it's still the basic principle of folding, but according to different people, it happens in different ways. It's a different model. (Jean, pre-interview, 3/29/02, line181)

> I think what I mean is if it's not, if it's still something that wasn't there. They could both work because they're both questioning something different. So they're making people think of other ideas. I think that's what I meant. Like if it's not, if it's not accepted as truth yet, these other models and interpretations are probably good. (Jean, pre-interview, 3/29/02, line207)

Without using the term specifically, she implied that multiple models could be the result of competing theories.

Jean's view of multiple models for the same thing was rated as emerging-scientific since she made a clear reference to competing theories.

**Jean's Post-Module View of Multiple Models for the Same Thing (rating: 3)**

After the module, Jean's view of multiple models was rated as emerging-scientific. She again expressed the view that multiple models for the same phenomenon are related to different ideas or explanations about the same phenomenon. She made this point even more clear than she had in the pre-module interview by indicating that models of different forms that represent the same ideas are not really different models, whereas models that represent different ideas are indeed different models:

> I think if they make different relationships in the two ponds, the real pond and the computer, they are two different models. If we're trying to represent the same system just in a different way, with the same variables, the same relationships, I think that they're the same type of models. (Jean, post-interview, 4/29/02, line 549)

> I mean I'm sure there's different theories as to why. So if you built a system where there's relationships and like factors affecting that one theory, it's going to be different from another theory with other factors and other variables. So those would be two different models, I think. (Jean, post-interview, 4/29/02, line 581)

Jean's view of multiple models for the same thing was rated as emerging-scientific. It is not considered to be scientific merely because she has not acknowledged that different models for the same are possible of they focus on different aspects of that phenomenon.

**Jean's Pre-Module View of Validating Models (rating: 2)**

Prior to the outset of the module, Jean's view of validating models was rated as pre-scientific. She had very little to say about how models are validated or tested. When discussing this aspect of models and modeling, she referred to hypothesis testing, a prevalent means for establishing the legitimacy of scientific explanations and one that can be associated with modeling. Her reference was more related to science in general though:

M: I mean how do they know that their model is, explains the phenomenon?

J: I think what most scientists, well, from what I understand, is that they don't necessarily try to prove something. They try to find things to negate something to like make it not work. And until they find something that shows that it wouldn't, that their theory isn't right and until there's an instance that, that shows that it (the mechanical arm) does bend that way, I think they would take that as, as what is common. (Jean, pre-interview, 3/29/02, line123)

Jean's view of validating models was rated as pre-scientific. It is scientific in the sense that modeling can include hypothesis testing, but a model itself is validated while it is being developed through its agreement with empirical observations.

**Jean's Post-Module View of Validating Models (rating: 3)**

After the module, Jean's view of validating models was rated as emerging-scientific. She expressed two contrasting views of validating a model. First, she suggested testing out the predictions of a model on a miniature pond. Her reasoning was that she might not want to compare it to the behavior of the actual pond under study for fear of destroying a large ecosystem. In essence, she suggests comparing the behavior of a model to the behavior of a real system. On the other hand, she seems to value what a "real" smaller version of the system of interest might suggest more than what a model might predict:

> I mean like instead of going out to this actual big pond, and like you know boiling the water in it or whatever to see what happens, um, if you just have a little pond in your yard, like maybe not even a pond like a little, put fish in it, put you know plants in it, and alter it that way. It's a smaller scale but it still represents a pond. And then if you mess up or if you kill things, it won't, it's only a little bit. (Jean, post-interview, 4/29/02, line 377)

Jean was able to explain how a weather model could be validated. She suggested that one could see if the model correctly predicts previous days' weather:

> . . . before you can know that you're right with the relationships that you're making maybe like, days that have already happened. What happened on yesterday and get readings of what the temperature was, what the moisture was, like data from that day when you know what the result is. And then make relationships, yielding that result and then maybe you can be more accurate knowing that it's working. (Jean, post-interview, 4/29/02, line 424)

An interesting offshoot from the focus on testing and validating models that came up during the post-module interview was Jean's indication that she would trust something real (like a miniature pond) versus something based on her assumptions (her pond model):

> I think I would trust my results if I had a real pond and did this stuff for real. I mean however hard it might be, but if I did it for real rather than trust something based on a lot of my assumptions. (Jean, post-interview, 4/29/02, line 564)

She appears to fail to recognize that many of the relationships she built in her model (such as the relationship between dissolved oxygen and temperature) were in fact based on well-established scientific laws.

Jean's view of validating models was rated as emerging-scientific since she explained that in order to test a model, its behavior must be compared to the behavior of the target phenomenon.

**Discussion about Jean's Modeling Understandings**

Jean's understandings of scientific models and modeling became more scientific in 4 out of 5 dimensions. Prior to the model, she primarily held an instructional aid view of models, although she did acknowledge that they could be used as a thinking tool by someone trying to understand the phenomenon him or herself versus using it to explain it to someone else. Jean's views regarding building models were commensurate with the purposes she ascribed to models. For instance, when explaining things to others, the model would need to be of appropriate detail. Jean equated particular models with particular modelers' ideas. Yet, she appeared to view models as final form entities that get changed as new discoveries are made.

After the module, Jean appeared to have concretized her pre-module view that models could be used to gain insight about a phenomenon via manipulating variables and seeing how the modeled system behaves. She appeared to recognize that a connection between the behavior of a model and the behavior of the target needed to exist when building and testing models and that agreement in that behavior may prompt changes in the model. Prior to the outset of the module, she believed that models are related to the modeler's ideas and continued to hold that view, especially as it relates to multiple models. Jean continued to express a connection between multiple models and competing theories or ideas.

Even though her views became more scientific, Jean did not appear to hold scientific views about the role of models in science. She did not clearly indicate that the process of building and testing models is a means by which the modeler can learn about how the target phenomenon behaves. She appeared to believe that modeling is a means by which new knowledge could be generated but could not articulate how that occurs.

### 5.2.7 Clyde

A comparison of the ratings of Clyde's pre- and post-module modeling understandings can be seen in Table 5.7.

**Table 5.7**
*Ratings of Clyde's Pre/Post Modeling Understandings*

| | pre-module understandings | | | | post-module understandings | | | |
|---|---|---|---|---|---|---|---|---|
| **DIMENSION** | **1** | **2** | **3** | **4** | **1** | **2** | **3** | **4** |
| **PURPOSE OF MODELS** | | | | √ | | | | √ |
| **BUILDING MODELS** | | | √ | | | | √ | |
| **CHANGING A MODEL** | | | | √ | | | | √ |
| **MULTIPLE MODELS FOR THE SAME THING** | | | √ | | | | | √ |
| **VALIDATING MODELS** | | | | √ | | | | √ |

**<u>Clyde's Pre-Module View of the Purpose of Models (rating: 4)</u>**

Prior to the outset of the module, Clyde's view of the purpose of models was rated as scientific. Clyde suggested that they could be used for both research and teaching. Regarding the latter, he explained that models would be used with students if the actual phenomena being studied were inaccessible:

> I thought a scientific model would be built in, in case you couldn't get to an actual area of the phenomenon or to use it in a classroom sense so that you don't actually have to be there. (Clyde, pre-interview, 3/29/02, line 21)

For research, Clyde suggested that experiments could be conducted on the model and that what is learned about the behavior of the model could be applied to the phenomenon:

> C (Clyde): Well, if you have a model that you can experiment on, then maybe you can make further conclusions and then maybe actually take them out to the field like as a first run.
> M (Interviewer): Oh, okay. So, if you, you find out how the model behaves . . .
> C: Try to . . . and then take what the model, how the model behaves and apply that to the actual phenomena. (Clyde, pre-interview, 3/29/02, line 31)

He used the example of ideal gases, imaginary entities whose behavior can be predicted based on some fairly simple principles. Clyde explained that the behavior of real gases could be understood by comparison with ideal gases.

Clyde also explained that scientists build simulations on computers and that doing so helps them to understand the phenomenon they are modeling, which can be used when direct investigation is cost prohibitive. He added that computer simulations could be used, as with flight simulators, for example, to gain comfort with the target phenomenon prior to experiencing it for real:

> One might be to, to get the students or researchers comfortable with the subject before they actually go in and do it. Like another, another thing with this NASA thing is where they actually do, use flight simulators and such before they actually let them touch an expensive rocket or something. (Clyde, pre-interview, 3/29/02, line 192)

Clyde's view of the purpose of models is rated as scientific since he recognized that a model is a tool used in the generation of knowledge or understanding about a phenomenon.

**Clyde's Post-Module View of the Purpose of Models (rating: 4)**

After the module, Clyde's view of the purpose of models was rated as scientific. He suggested that models were used when the target could not be easily and directly examined. He added that models could be used in cases where direct exploration of the target phenomenon was dangerous (chemicals), expensive (space exploration), or where time and materials could be saved (in the case of finding cancer cures derived from rare plants in remote locations around the world). He also commented that models would have to be used to study phenomena like dinosaur extinction because dinosaurs cannot be studied directly since they no longer exist. Carl described two essential functions of models. First, he described using models to examine what might happen to certain variables associated with a phenomenon when others were changed or varied without having to make them happen to the actual system:

> But here (with a computer model) we could use it to study what effects certain changes would make without having to make them physically there. (Clyde, post-interview, 4/30/02, line 20)

He then suggested that models could be used in an intermediate step in research whereby possible scenarios could be tested out on a model prior to their being carried out on the actual phenomenon. In this way, identifying situations or conditions that were especially promising could save time and resources:

> . . . maybe I would do that because of expense or safety . . . if I remember it right, it was used to pick the best or see if it would work before carrying it out . . . it was used like, it was like an intermediate step in the process to make sure that you were getting out what you wanted. (Clyde, post-interview, 4/30/02, line 99)

Clyde's view of the purpose of models was rated as scientific since he indicated that information about the target is gleaned from working with the model and that the model can be used in place of the target.

**Clyde's Pre-Module View of Building Models (rating: 3)**

Prior to the outset of the module, Clyde's view of building models was rated as pre-scientific. Clyde made suggestions about building models related to both educational uses as well as for research uses. Regarding the latter, he acknowledged that the process of building a model would include carefully studying a phenomenon and trying to accurately represent the characteristics of the phenomenon with the model:

> In research it would have to be more exact than what it's representing. It would have to show all the, at least all the characteristics that you're looking at studying. It would have to accurately represent those characteristics that are in the actual . . . . (Clyde, pre-interview, 3/29/02, line 105)

He added that certain aspects of the target could be omitted if they did not have a bearing on the aspect of the target's behavior that was being studied.

Clyde's view of building models was rated as emerging-scientific instead of scientific because he did not acknowledge the iterative nature of modeling.

**Clyde's Post-Module View of Building Models (rating: 3)**

After the module, Clyde's view of building models was rated as emerging-scientific. Clyde again acknowledged that the process of building a model would include carefully studying a phenomenon and trying to accurately represent the characteristics of the phenomenon with the model:

> . . . consider the relationships that exist between subjects being studied and the real phenomena that exist in nature. (Clyde, post-questionnaire)

He also again suggested that certain aspects of the target could be omitted if they did not have a bearing on the aspect of the target's behavior that was being studied.

Clyde's view of building models was again rated as emerging-scientific instead of scientific because he still did not acknowledge the iterative nature of modeling.

**Clyde's Pre-Module View of Changing Models (rating: 4)**

Prior to the outset of the module, Clyde's view of changing models was rated as scientific. He suggested that models are changed when the predictions of the model are not in agreement with observations of the target:

> Well, if the, if it comes up as invalid, then they didn't represent something in the . . . they either misunderstood or didn't consider something in the actual phenomena that's relevant to actual data they collected. (Clyde, pre-interview, 3/29/02, line 154)

Clyde's view of changing models was rated as scientific.

**Clyde's Post-Module View of Changing Models (rating: 4)**

After the module, Clyde's view of changing models was rated as scientific. Clyde suggested that models are changed when the predictions of the model are not in agreement with observations of the target. He made an explicit reference to observing the pond models, suggesting that the relationships in the model would need to be changed if they "didn't hold up" after observing the actual pond:

> Well, for example for us I'm, I'm trying to remember. I know we have the first model there too. We, after we went out to the pond the second time, we found that some of the relationships we had built didn't hold up. And so we went back though and we took out the ones that didn't work and we changed the ones that needed changed. And then we felt that it more accurately represented what actually happened." (Clyde, post-interview, 4/30/02, line 177)

Clyde's view of changing models was rated as scientific.

**Clyde's Pre-Module View of Multiple Models for the Same Thing (rating: 3)**

Prior to the outset of the module, Clyde's view of multiple models was rated as emerging-scientific. He suggested that different models for the same phenomenon might be used in order to focus on different aspects of the phenomenon:

> C: Well, one might not have everything, every different or variable.
> M: So, you're saying one might be more complex than the other?
> C: Yeah. Or maybe they might have several on equal complexities but different things are modeled in each, different characteristics, specific characteristics. (Clyde, pre-interview, 3/29/02, line 166)

He imagined breaking a complex phenomenon down into smaller parts in order to focus on individual aspects of the phenomenon. He added that the model could then be "reconstructed" from the individual parts.

Clyde's view of multiple models for the same thing was rated as emerging-scientific because, although he recognized that different aspects of a phenomenon could be the focus of different models, he did not acknowledge that different models might represent different or competing theories or explanations.

**Clyde's Post-Module View of Multiple Models for the Same Thing (rating: 4)**

After the module, Carl's view of multiple models was rated as scientific. Clyde again discussed different models for the same phenomenon that might be used in order to focus on different aspects of the phenomenon:

> Well, if you are using a simple model, you're looking at a small number of relationships. And so you're studying maybe one aspect of the phenomenon. Or either you're studying just a small part of something in nature . . . . (Clyde, post-interview, 4/30/02, line 230)

He added that models of varying complexity might be used depending on how specific the desired results were. Clyde also suggested that different models for the same phenomenon might arise by modelers applying known information in different ways. He explained that this would be the result of building different relationships into their models:

> Just by applying the evidence that you have in different ways, I guess, and building different sets of relationships with that knowledge. (Clyde, post-interview, 4/30/02, line 530)

Clyde's view of multiple models for the same thing was rated as scientific since he indicated that different models could arise from different ideas about how the target behaves or from the modeler's desire to focus on different aspects of the same phenomenon.

**Clyde's Pre-Module View of Validating Models (rating: 4)**

Prior to the outset of the module, Clyde's view of validating models was rated as scientific. He suggested that models are validated via testing to see if the data generated by the model match the data collected on the target. He added that if they are not in agreement, then the model is invalid and must be revised. Clyde suggested that results that are not in agreement would indicate that the modeler had misunderstood the behavior of the target or had neglected to include an important factor in the model. Thus, working with the model would help the modeler understand the phenomenon:

> M: How would you test it?
> C: By running it and seeing if the data that it presents is the same as the data that you collected.

M: Oh, okay. So you would somehow or other see what the model predicts?
C: Yeah.
M: And then compare . . . .
C: Compare it.
M: . . . that to whatever the phenomenon is?
C: Yeah.
M: Now suppose the, suppose the model predicts something then the data shows.
C: Something contrary to it?
M: Yeah.
C: If it predicts something contrary to it, your simulation isn't valid and you have to retool. (Clyde, pre-interview, 3/29/02, line136)

Clyde's view of validating models was rated as scientific since he clearly explained that a model is validated via comparison between the behavior of the model and the target.

**Clyde's Post-Module View of Validating Models (rating: 4)**

After the module, Clyde's view of validating models was rated as scientific. Clyde suggested that models are validated by comparing the predictions made by the model with observations of the target phenomenon. If the two were in agreement, Clyde suggested that the model could be considered accurate. He acknowledged that this was not necessarily the case when asked to clarify his comments. If the model's predictions and observations of the target were not in agreement, Clyde suggested that the model would need to be revised:

C: By, by like working out your model, either going out in the field and studying that first and then building your model and then seeing what your model predicts and then going out and studying different relationships you know of in nature without doing any damage. Studying what, what goes on there versus what your model predicts and seeing if they coincide.
M: And if they do?

C: If they do, then your model is accurate to what you're studying. And if they don't, then you know there's an error somewhere that you need to fix. (Clyde, post-interview, 4/30/02, line 124)

Clyde also indicated that a model could be considered to be valid if it made correct predictions a high percentage of the time (referring to weather models).

Clyde's view of validating models was rated as scientific since he explained that a model is validated via comparison between the behavior of the model and the target.

**Discussion about Clyde's Modeling Understandings**

Clyde's understandings of scientific models and modeling changed very little. He expressed sophisticated views prior to and after the module. There are only two areas where his views seemed less than scientific after the module. First, with regard to building models, Clyde never acknowledged that modeling is an iterative process that requires cycles of testing and revising models. Second and perhaps more importantly, he only briefly alluded to using a model to figure out the behavior of a model in the sense of trying to get the Model-It to behave like a model in order to understand the target. Clyde seemed more inclined to view a model as something that could be used to investigate what might happen to the target under various conditions. This is certainly a scientific view of the use of models, but slightly more aligned with an engineering or design view of modeling.

### 5.2.8 Marvin

A comparison of the ratings of Marvin's pre- and post-module modeling understandings can be seen in Table 5.8.

**Table 5.8**
*Ratings of Marvin's Pre/Post Modeling Understandings*

| | pre-module understandings | | | | post-module understandings | | | |
|---|---|---|---|---|---|---|---|---|
| **DIMENSION** | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| **PURPOSE OF MODELS** | | | √ | | | √ | | |
| **BUILDING MODELS** | | | √ | | √ | | | |
| **CHANGING A MODEL** | | | √ | | | | √ | |
| **MULTIPLE MODELS FOR THE SAME THING** | | √ | | | √ | | | |
| **VALIDATING MODELS** | | √ | | | | | √ | |

**Marvin's Pre-Module View of the Purpose of Models (rating: 3)**

Prior to the outset of the module, Marvin's view of the purpose of models was rated as emerging-scientific. Marvin expressed what could be called an engineering view of models. In this view, a model is used in the design process. Different designs are incorporated into models that are tested. The most promising or successful designs are then put into production of the actual target device or entity:

> Well, the model would help them in terms of they would be able to see . . . well, if you take the different designs of a shuttle and they would, they would check the air flows over the tunnel. They would see different designs, and they would take the one that was streamlined that would give the, the shuttle the best penetration through the, the air. (Marvin, pre-interview, 3/29/03, line 89)

Marvin acknowledged that such designs could be physically built (such as model airplanes whose aerodynamics could be tested in a wind tunnel) or built and tested on a computer. He was unable to elaborate on the computer type though. He recognized that what is learned from manipulating the model can be applied to the target:

> . . . I think I said a model is something that you design ahead of time that you try to reflect how, you know, it reflects something that will actually be applied in the real world. (Marvin, pre-interview, 3/29/03, line 566)

Marvin was confronted during the pre-module interview with some models that have been developed in his discipline of physics (e.g., the wave and particle models for light), but he did not appear to recognize these as models.

Marvin's view of the purpose of models, while different in many respects from the kind of model used in the development of scientific explanations (versus the engineering/design kind), was rated as emerging-scientific.

**Marvin's Post-Module View of the Purpose of Models (rating: 2)**

After the module, Marvin's view of the purpose of models was rated as pre-scientific. In the post-module interview, Marvin only made one reference to an engineering/design type model. Instead, he expressed a view of models as visual aids for helping a learner (a student or another scientist) understand difficult to see concepts:

> Well the purpose of it is to give a student or, or the learner a visual, a visual concept of what something looks like. (Marvin, post-interview, 5/1/03, line 40)

He demonstrated an instructional view of models:

> M (Interviewer): So how would science, how do scientists use a, a model of light?
> MA (Marvin): How would they use it? Well they would use it, they would use it to explain how light moves and it goes through a medium.

M: Okay, so scientists use models to explain how, to explain things to whom?

MA: To, to explain things to how, to anybody who wants to learn about it, to a learner or to a student. But they might use it to, to, for other scientists too who don't . . . if they're trying to teach something new, a new concept or a new theory, they might use it to bridge the gap. (Marvin, post-interview, 5/1/03, line 67)

When asked to consider scientists using pond models like the ones built during the module, Marvin suggested that computer models could be used to explore what would happen to an ecosystem under various conditions and to find ideal conditions:

> Well, a scientist is, is probably looking at trying to make the environment in this pond better. And he wants to, and they want to figure out what variables or what's causing it to either deteriorate or get better to keep it, maintain it. So this would be an excellent way of studying what, you know what's, what's causing a problem or what's helping it be the way it is so they can maybe find an ideal situation with this model or they can find, use this to identify a, a pond that's deteriorating to find out why it's deteriorating. (Marvin, post-interview, 5/1/03, line 308)

Frankly, Marvin's views were extremely inconsistent and difficult to decipher at times. At one point, he even questioned whether or not building models using the Model-It was actually model building at all. He also acknowledged that various models of the structure of atoms have nothing in common with actual atoms, yet agreed with numerous positive analogies when they were pointed out to him.

Marvin's view of the purpose of models was rated as pre-scientific because, although he did express the scientific view that models could be used to explore "what if?" scenarios, he believed that their primary function was as visual aids for making explanations.

**Marvin's Pre-Module View of Building Models (rating: 3)**

Prior to the outset of the module, Marvin's view of building models was rated as emerging-scientific. Marvin described a process in which different iterations of a model would be developed until an acceptable or optimal design was achieved, at which time an actual device would be created. He indicated that real-world principles, as they were understood, would inform the design of the model:

> MA: It helps you make a better model. Improve on your, on your existing model till you get to the best one you can possibly have.
> M: Right. But I mean that helped . . . you're, you're saying that once you. . . .once you understand what happens to the model then you'll know what will happen to the, the real shuttle?
> MA: Right. Then you . . . yeah, you can generalize that to, to the, a real situation. (Marvin, pre-interview, 3/29/03, line 101)

Marvin's view of building models was rated as emerging-scientific since he clearly recognized modeling as an iterative process and acknowledged a connection between the behavior of the model and the behavior of the target.

**Marvin's Post-Module View of Building Models (rating: 1)**

After the module, Marvin's view of building models was rated as limited. Marvin suggested that the best model duplicates the real thing in order to "get your point across (post-interview, line 216)." He added that the complexity of a model is dependent upon the audience:

> Well, because they're probably . . . their, their audience is different than our, than our audience. So they're dealing with people that are experts in their fields. They probably come up with more, more complicated models. (Marvin, post-interview, 5/1/03, line160)

Marvin did not articulate a process for building models per se but did indicate that data collected on the target phenomenon would go into the model and that the model is only as good as the data collected:

> Well, your model is only as good as your data that you collect. If you put in, you know, inappropriate data, your model is not . . . it's going to produce a wrong result. (Marvin, post-interview, 5/1/03, line 517)

He added that the modeler must know the phenomenon being modeled inside and out. Referring to building pond models, Marvin indicated that the modeler would have to know cause and effect relationships.

Marvin's views of building models were rated as pre-scientific since he expressed some limited, some pre-scientific, and some emerging-scientific views. He did make a connection between empirical data with respect to the target and the model. He also alluded to the importance of relationships among variables. Still, the main function Marvin attributed to models was to "get a point across," which carried over to his view of how models are built.

**Marvin's Pre-Module View of Changing Models (rating: 3)**

Prior to the outset of the module, Marvin's view of changing models was rated as emerging-scientific. Marvin implied that changing models was an important, inevitable aspect of the design process (see pre-module comments related to purpose and building models above). He made explicit connections between examining the performance of the model and making adjustments and adaptations to improve that performance until an acceptable or optimal design was achieved.

Marvin's view of changing models was rated as emerging-scientific since he acknowledged that models are subject to change. In this case, the behavior of the model is compared theoretically to the desired behavior of the target.

**Marvin's Post-Module View of Changing Models (rating: 3)**

After the module, Marvin's view of changing models was rated as emerging-scientific. Marvin suggested that if the behavior of a model was different than the behavior of its target, then it would need to be changed or revised:

> M: So, I would, I would, I would, I would . . . my model would make a prediction. I would go out to the field and see if the conditions out there are what my model predicts.
> MA: Right.
> M: And then, if not, then I would, after I would revise my model?
> MA: Well, you're going to have to . . . there's something that you have to include in your model. (Marvin, post-interview, 5/1/03, line 439)

He was able to apply the same rationale for changing a pond model to using models for predicting weather.

Marvin's view of changing models was rated as emerging-scientific since he acknowledged that models are subject to change and made a connection between the agreement of the behavior of the model and the target.

**Marvin's Pre-Module View of Multiple Models for the Same Thing (rating: 2)**

Prior to the outset of the module, Marvin's view of multiple models was rated as pre-scientific. Marvin equated multiple models for the same target with multiple designs that could be tested. He was unable to discuss this in specific terms or provide any concrete examples. It was unclear whether he viewed different designs as existing simultaneously or as being different iterations during the design process. He also alluded to different models as being of different complexity depending on whomever was using them:

> M: Because you got to have some kind of a mental concept in your head of whatever you're talking about. And if you don't provide that to a student or to anybody, that student is going to come up with his own, with his own mental concept of that, of that model.
> M: Would a scientist use that?
> MA: Yeah.
> M: How would they use it? I mean I, you just said that you would use it to explain it to a student but how would a scientist use it?
> MA: Well, I think a scientist would be at a higher level and he might be using it in a way to apply it to, to something else, maybe apply it to new material, apply it to a testing velocity of another material. (Marvin, pre-interview, 3/29/03, line 420)

It is interesting to note that Marvin also suggested that numerous "copies" of a model would be needed for various tests in the event one was damaged or destroyed.

Marvin's view of multiple models for the same thing was rated as pre-scientific since he did indicate that there could be different designs for the same device but failed to indicate specifically what might make them different.

**Marvin's Post-Module View of Multiple Models for the Same Thing (rating: 1)**

After the module, Marvin's view of multiple models was rated as limited. Marvin's views related to this dimension were very difficult to characterize. He suggested that if two different models produced the same results, it would provide supporting evidence for a certain view or explanation:

> Well, if you use, if you have a method and I have a method and we end up with the same results of two different models, I would think that would be

> even more proof that it's something really true. (Marvin, post-interview, 5/1/03, line 552)

The implications of his statements are unclear. Marvin was unable to offer any other reasons for more than one model for the same phenomenon. Therefore, his view of multiple models for the same thing was rated as limited.

**Marvin's Pre-Module View of Models (rating: 2)**

Prior to the outset of the module, Marvin's view of validating models was rated as pre-scientific. Marvin's engineering/design view of models implied much about his view of validating models. Examining the performance (testing) of different designs would necessarily be a major component of his view since that would be the means for evaluating which design was best. Marvin was unable to articulate how other kinds of models might be tested or validated.

Marvin's view of validating models was rated as *pre-scientific* since he recognized the importance of testing and validating models but could not make a connection between observations of the model and the real world.

**Marvin's Post-Module View of Validating Models (rating: 3)**

After the module, Marvin's view of validating models was rated as emerging-scientific. He suggested that the way to establish the validity of a model was to compare it with observations of nature:

> M: Okay. So, how do I know if this model is working like the Tait Farm pond?
>
> MA: Okay. Well, what you would probably have to do is maybe, maybe do like three or four data collection situations, go out and collect data over a period of three years and keep, you know, go back and compare your data with what your results are. (Marvin, post-interview, 5/1/03, line 431)

He did so by indicating that a model is only as good as its predictive value. He added that repeated correct predictions add to the validity a model:

> I would say your model is good after three years if you kept going out and getting, getting the right results. (Marvin, post-interview, 5/1/03, line 455)

Marvin was able to apply these principles for validating a model to weather models as well as the pond models built during the module.

Marvin's view of validating models was rated as emerging-scientific since he acknowledged the importance of comparing the behavior of the model and the target.

**Discussion about Marvin s Modeling Understandings**

Marvin's views of the purpose of models prior to and after the module were very different, but not necessarily more scientific. His views appeared to be more scientific in some dimensions and less scientific in others. Prior to the module, Marvin possessed an engineering view of models. He viewed models as "mock-ups" of a real entity that could be used for the purpose of testing various designs. He viewed this as an iterative process and clearly articulated a view that suggested that what was learned about the model could be applied to the target. These are fairly sophisticated views. Marvin did not, however, view modeling as a means for learning about a target that already existed or was not understood.

After the module, Marvin's views were very inconsistent. The primary function he assigned to models was as visual aids for use in teaching. At the same time, and depending what context he was considering, he did express some fairly sophisticated views that were inconsistent with viewing a model as a teaching tool. He recognized that models could be used to explore "what if?" scenarios regarding the effect on an ecosystem of changing certain variables. He appeared to understand that a model must be validated based on comparisons between the model and its target, and would need to be changed or revised if the behaviors of the two were not similar. Marvin's views about multiple models could not be ascertained from the interview.

Marvin was a bit of an enigma. While it is unclear exactly what his views were, it is clear that he did not view models as tools used to obtain information about a target that is inaccessible.

### 5.3 Assessment of the Models Built by the Prospective Teachers during Each Session

In this section, I address the second research question by presenting the results of my assessment of the models built by the pairs of prospective teachers during the first modeling session. The models built during the second session were each focused on answering different driving questions. Each model contains variables and relationships specific to that driving question, rendering comparisons among the models uninformative. During the first modeling session, the models should have been built to answer the same driving question. Each model was assigned two scores. The first, the quantitative score, reflects my assessment of the components of each model. The second, the qualitative score, reflects my assessment of the scientific accuracy and appropriateness of each model. A brief narrative accompanies each assessment. A description of the rationale and criteria used in the assessment of the models can be found in Chapter 4 of this thesis.

### 5.3.1 Jackie and Marvin

<u>**Jackie and Marvin, Session 1 Model (Quantitative Score: 52; Qualitative Score: 13)**</u>

The first model that Jackie and Marvin constructed contained 5 objects and12 variables (see Figure 5.1). One of the variables was actually a variable mistakenly defined for one object but meant for another. They did not delete the variable but instead

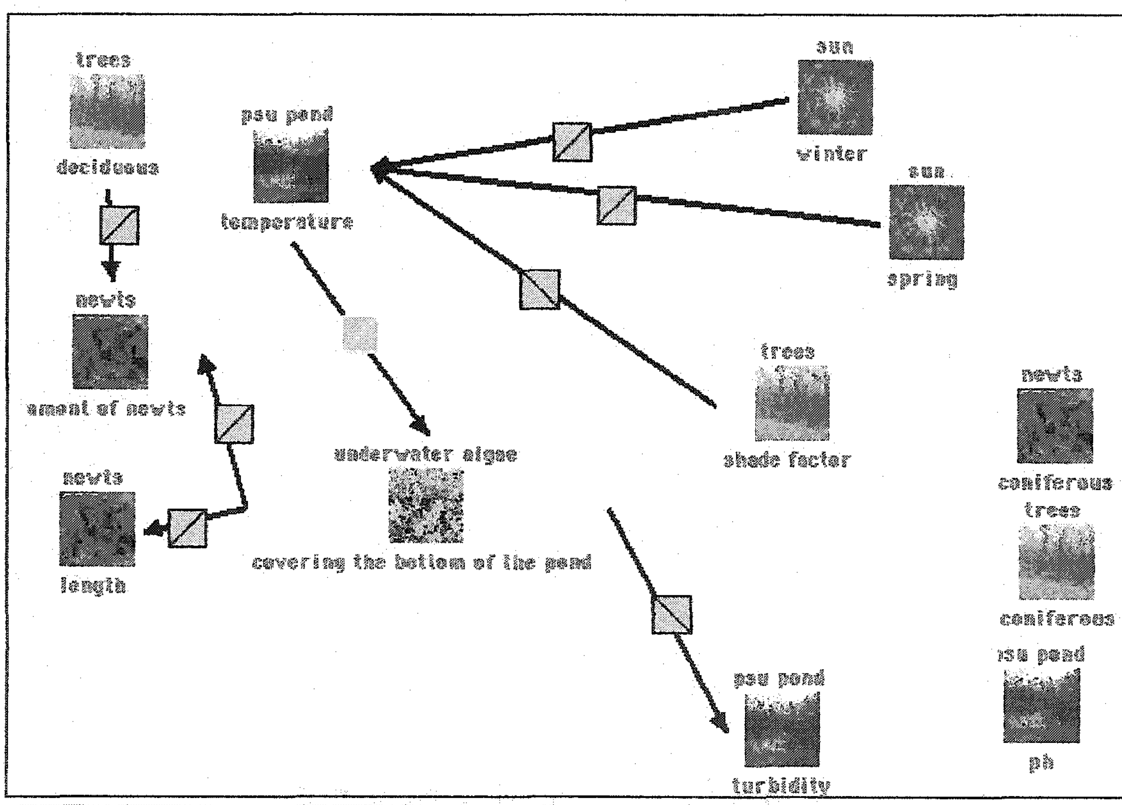



*Figure 5.1* **Jackie and Marvin's Session 1 Model**

made a new one and defined it for the correct object. Therefore they technically had 11 variables. They created 8 relationships with those variables. Two of the 11 variables were not used in any relationships. They had very little interconnectedness in their model. Only one variable affected more than one other variable and even in that case, it affected

2 similar variables for the same object (length and amount of newts, both of which actually describe the health of the newt population). They included only 3 of the 5 critical objects and 4 out of 7 critical variables. Jackie and Marvin had only one of the critical relationships in their model.

**Jackie and Marvin, Session 2 Model**

The second model, constructed entirely by Jackie due to Marvin's absence from class, also had very little interconnectedness. Again, only one variable affected more than one other variable. This model contained 6 objects, 8 variables, and 6 relationships (see Figure 5.2). The purpose of the second modeling activity was to revise the pond model

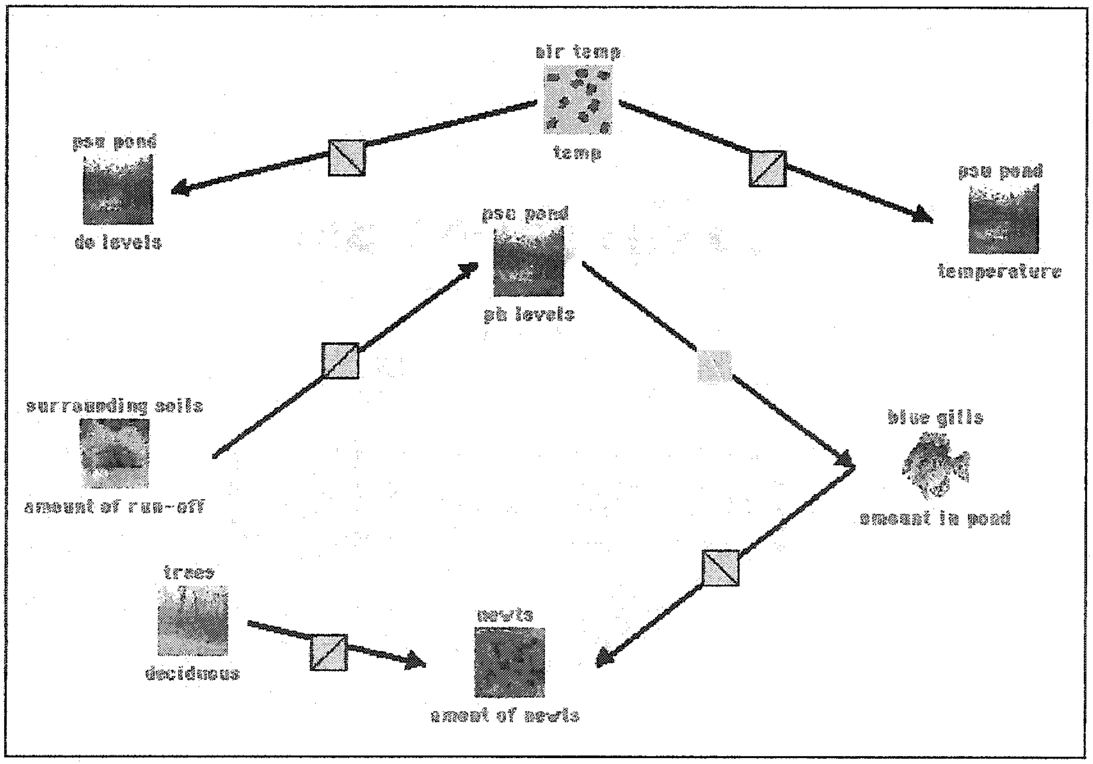



*Figure 5.2* **Jackie and Marvin's Session 2 Model**

based on the comparisons with the behavior of the second pond. Jackie basically started from scratch and built a brand new model.

### 5.3.2 Jane and Carl

**<u>Jane and Carl, Session 1 Model (Quantitative Score: 84; Qualitative Score: 29)</u>**

The model that Jane and Carl made contained 12 objects (see Figure 5.3). Three of the objects were not actually used in the model (air, shrubs, and dragonfly nymphs). Dragonfly nymphs and shrubs never had any variables defined for them. Of the 15

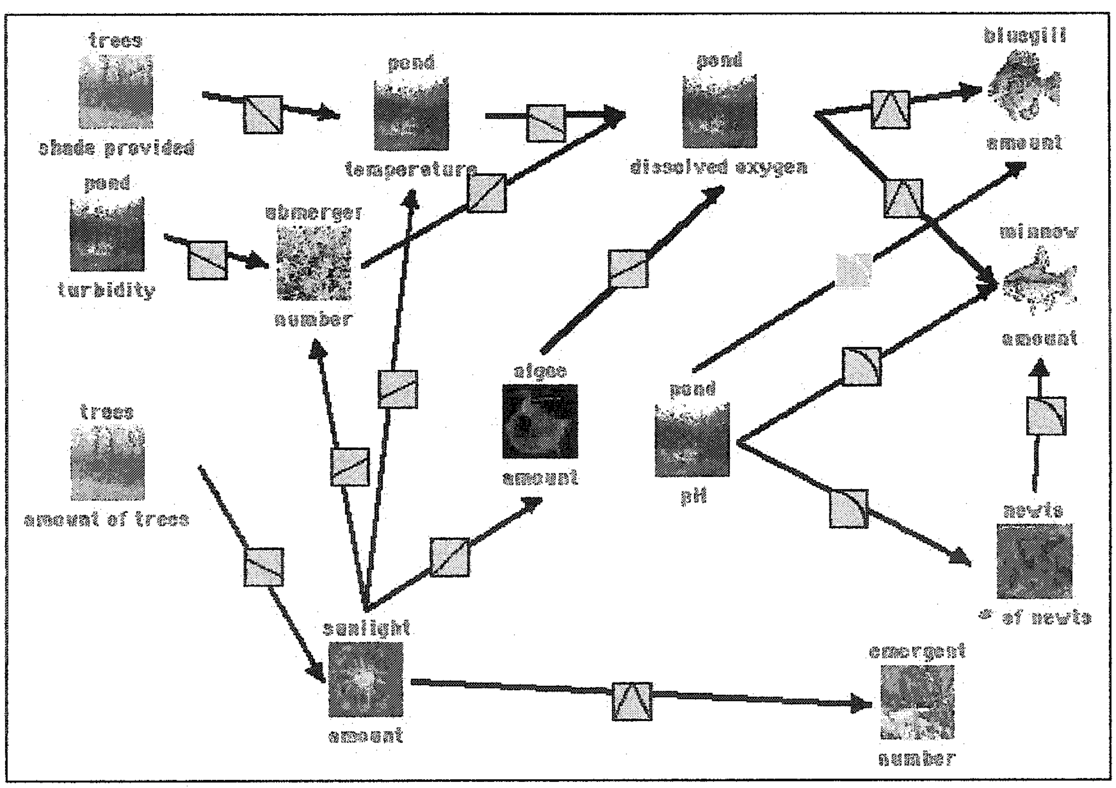



*Figure 5.3* **Jane and Carl's Session 1 Model**

variables they did define, 3 were not used in any relationships. They built 15 relationships. There was some interconnectedness with three variables being connected to more than one other variable. Jane and Carl included all of the critical objects and variables in their model. They failed to include two critical relationships, namely the two related to the food chain.

### Jane and Carl, Session 2 Model

The second model, constructed by Jane and Carl, consisted of 10 objects, 14 variables, and 16 relationships (see Figure 5.4). As mentioned in section 5.3.2, this model

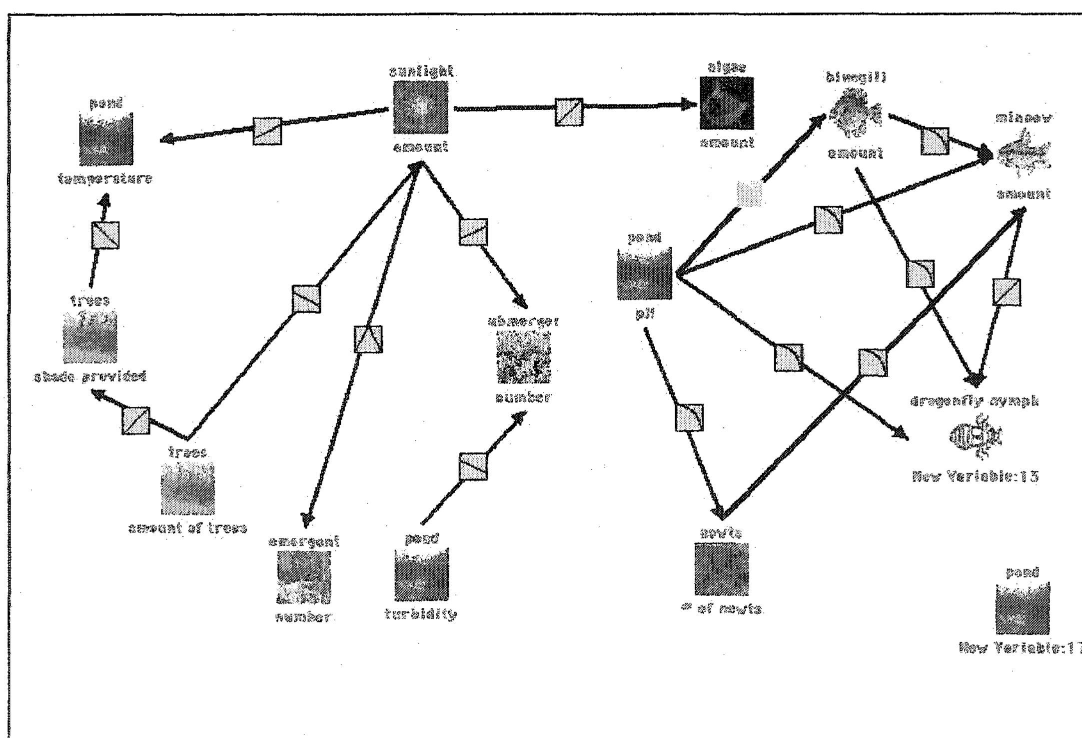



*Figure 5.4* **Jane and Carl's Session 2 Model**

was actually comprised of two separate models. The one they worked with was essentially a predator/prey model, using pH as the independent variable. There was some interconnectedness in the model resulting from the cyclic nature of predator/prey relationships. They may have chosen pH as an essential component of their model since we learned of the connection between the sources of the water in the two ponds and the closeness of the pH of each of those sources to the pH of the respective ponds.

### 5.3.3 Jean and Clyde

**Jean and Clyde, Session 1 Model (Quantitative Score: 68, Qualitative score 27)**

The model that Jean and Clyde built contained 7 objects (see Figure 5.5). All of the objects they created were used in the model. They defined 11 variables; all of which were used in relationships. Jean and Clyde built 12 relationships. There was some

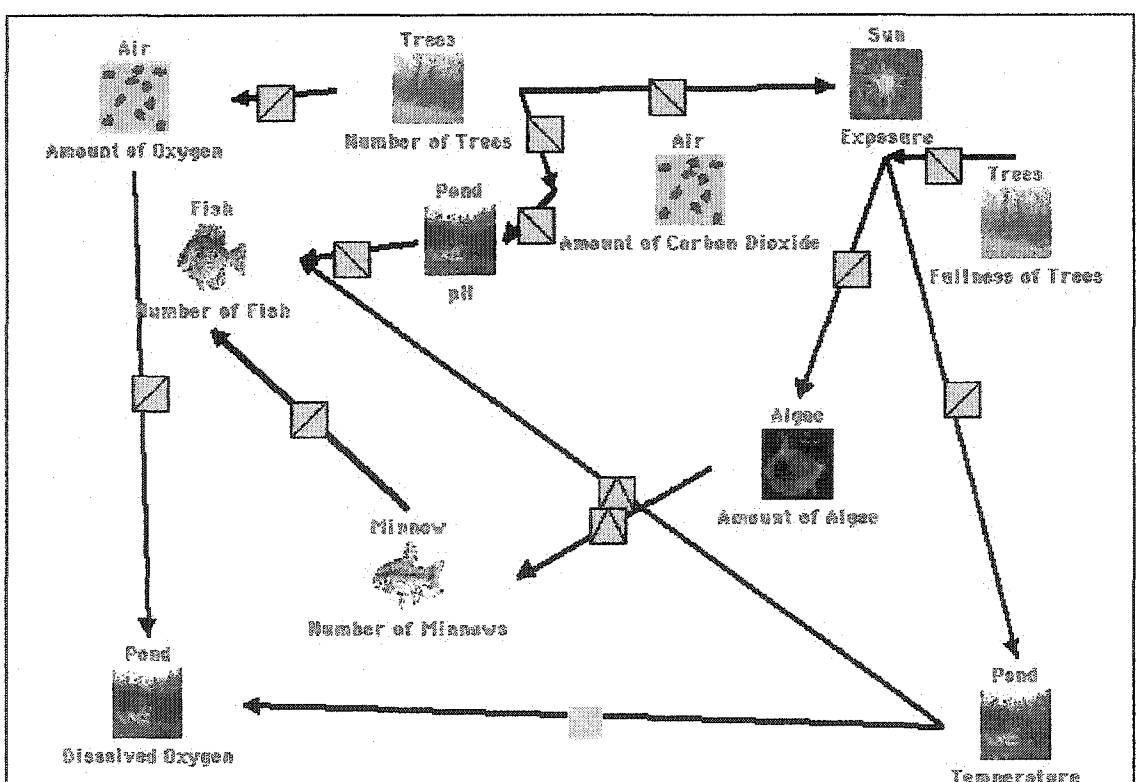



*Figure 5.5* **Jean and Clyde's Session 1 Model**

interconnectedness with three variables being connected to more than one other variable. They included all but one critical object (macroinvertebrates). They failed to include 3 critical relationships, namely the relationship between dissolved oxygen and fish, aquatic plants and dissolved oxygen, and a predator/prey relationship between macroinvertebrates and a food source for them.

**<u>Jean and Clyde, Session 2 Model</u>**

The second model constructed by Jean and Clyde consisted of 8 objects, 10 variables, and 13 relationships (see Figure 5.6). This model was very similar to their original model in

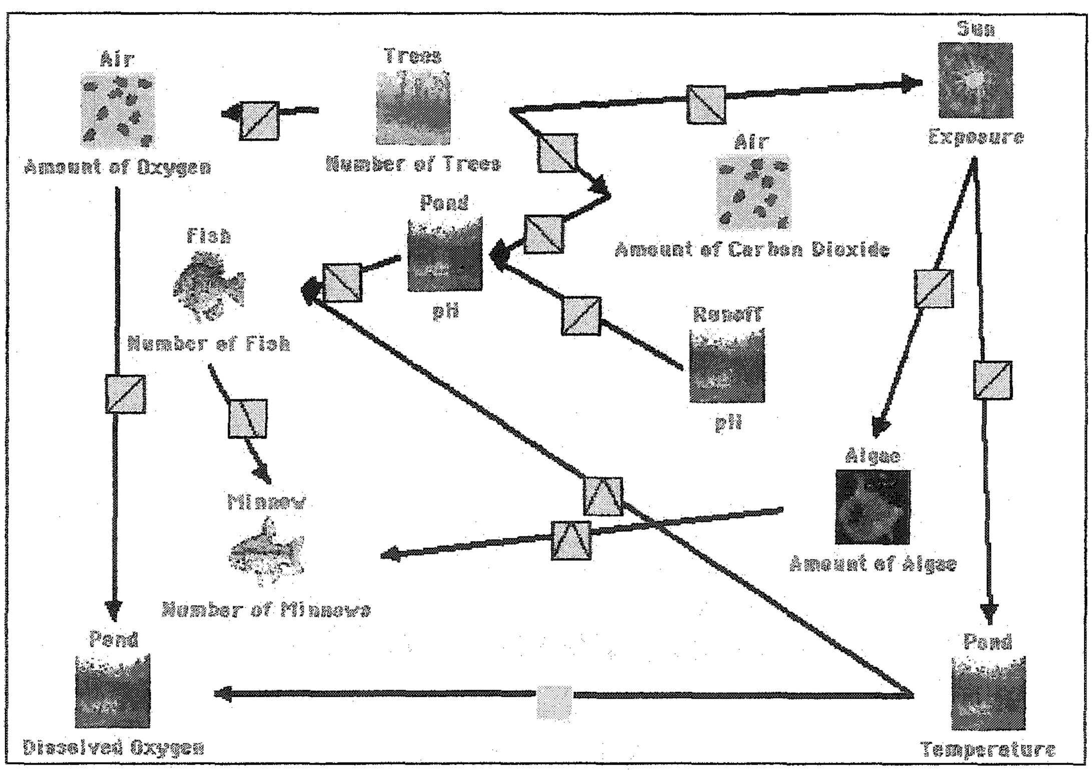



*Figure 5.6* **Jean and Clyde's Session 2 Model**

purpose since they appeared to be focused on seeing what would happen if the temperature of the pond was varied. The only object they added was "run-off" as they attempted to model the effects of the lower pond's main water source that accounted for the pond's pH. There was a limited amount of interconnectedness among the variables. Only two variables were connected to more than one other variable.

### 5.3.4 Kate and Matt

**Kate and Matt, Session 1 Model (Quantitative Score: 108; Qualitative Score: 33)**

The model that Kate and Matt constructed contained 11 objects. Every object was used in the model. Each object had at least one variable defined for it. Of the 12 variables they defined, each was involved in at least one relationship. They built 22 relationships. The model had a great degree of interconnectedness relatively speaking. There were 8

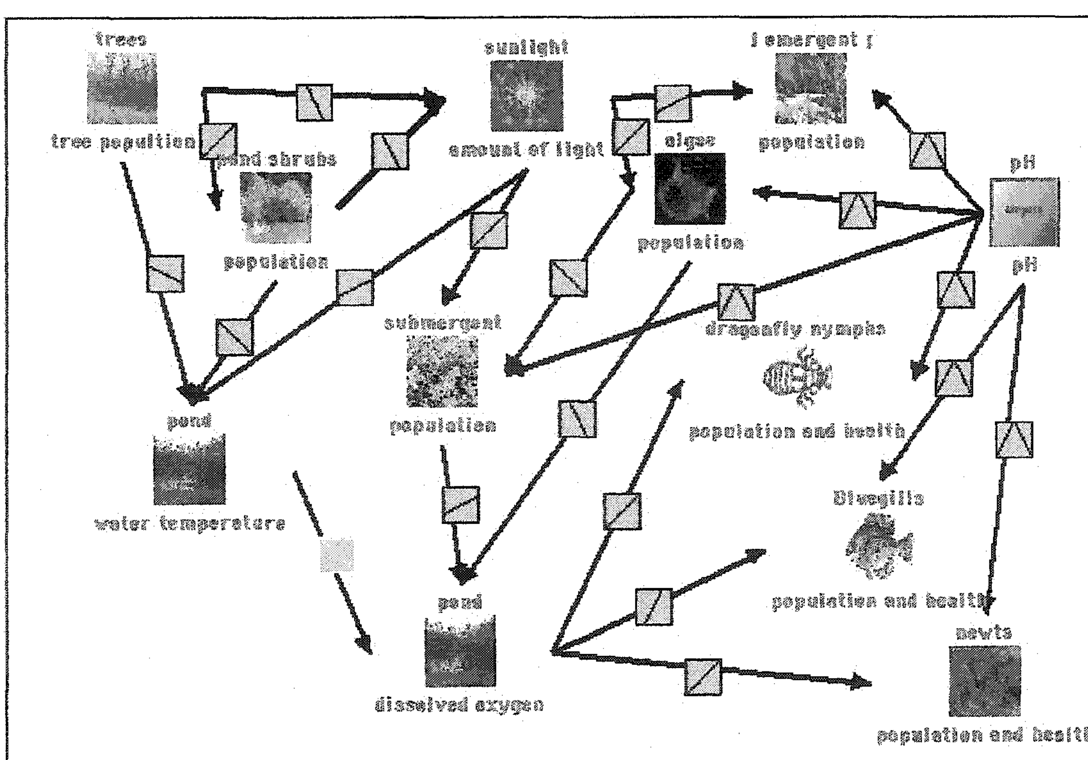



*Figure 5.7* **Kate and Matt's Session 1 Model**

variables that were connected to more than one other variable. The model included all of the critical objects and variables and most of the critical relationships. Kate and Matt did not include either of the food chain relationships.

**Kate and Matt, Session 2 Model**

The second model constructed by Kate and Matt consisted of 12 objects, 14 variables, and 33 relationships (see Figure 5.8). As mentioned in section 5.3.4, the model was essentially comprised of two models. One was the focus of the modeling session. Kate and Matt made few revisions to their original model. Instead they added to it significantly. The purpose of the model appeared to be to see what would happen to the second pond we visited if bluegills were reintroduced. We had learned that the bluegills

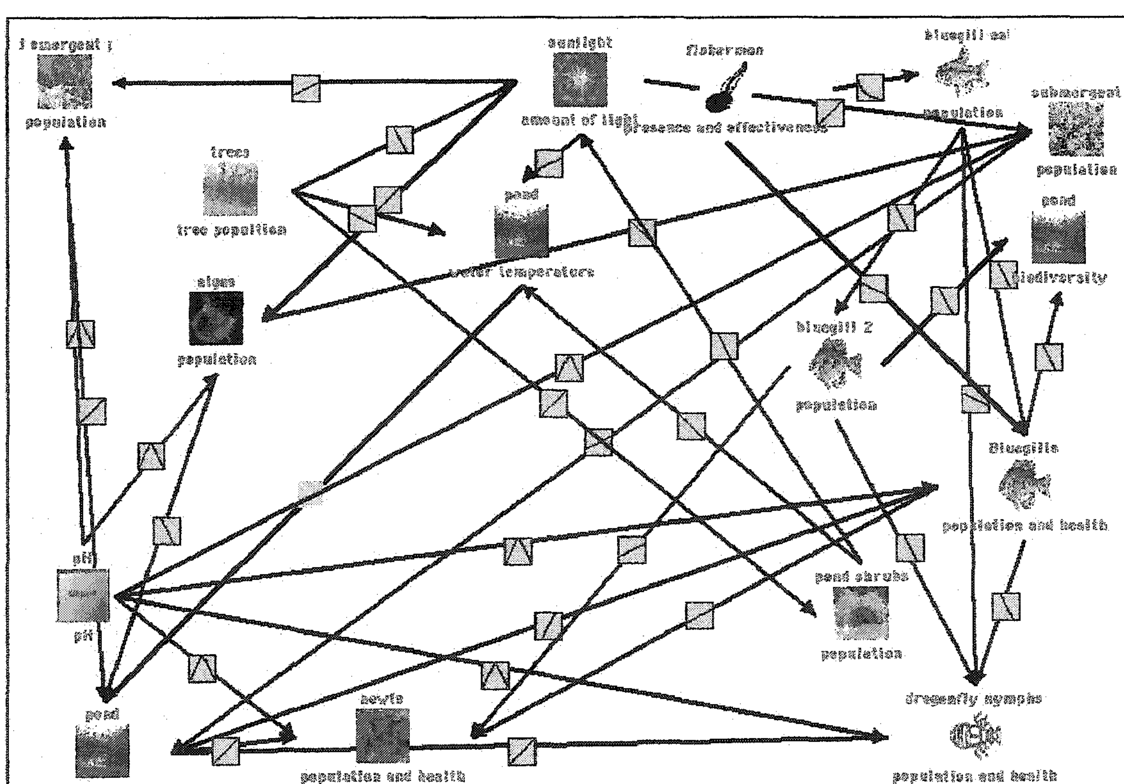



*Figure 5.8* **Kate and Matt's Session 2 Model**

in that pond had perished due to a drought. This information no doubt influenced the question they chose to investigate. Their model once again was characterized by a considerable amount of interconnectedness in the model.

**5.4 Profiles of the Prospective Teachers' Modeling Strategies**

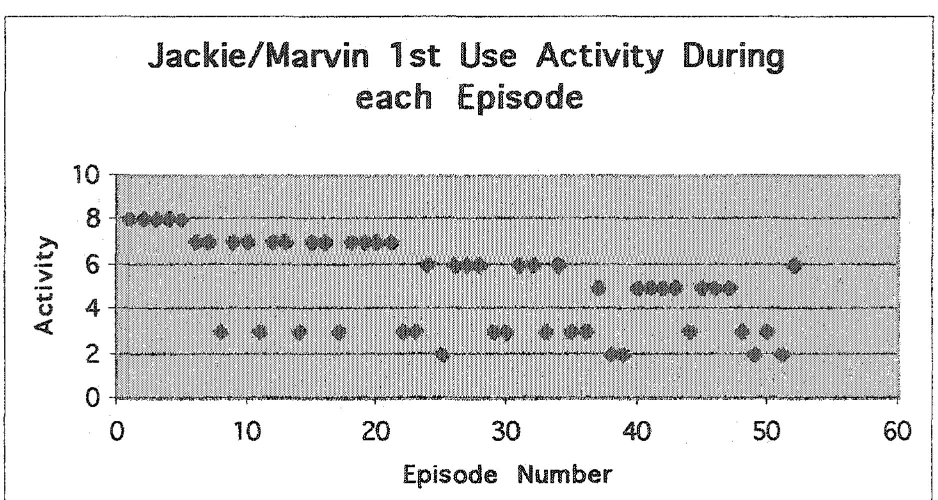
In this section, I address the third research question through a description of the manner in which the four pairs of prospective teachers constructed models using the dynamic simulation modeling software Model-It. The modeling activities of each of the four pairs of prospective teachers will be discussed in two subsections. The first subsection will be a synopsis of each of the two modeling sessions. The second subsection will focus on what was revealed during episodes from those sessions. The process used to identify and characterize those episodes was described in detail in Chapter 4 of this thesis. Each modeling session consisted of 40-80 episodes. Many episodes involved activities associated with building models such as choosing an object or defining a variable. Others involved discussions about what to do next or off-topic discussions. Such episodes may be of interest to researchers who do microanalysis of software use or discourse analysis. My purpose is to present revealing episodes that yielded insight into the prospective teachers' understandings of the nature of models and modeling, subject matter knowledge of pond ecosystems, and difficulties they may have been having with the Model-It software.

Each pair built their models during two separate sessions on two different days during the module. The primary purpose of the first modeling session, which occurred after the prospective teachers studied a pond in a wooded setting, was to address the driving question, "What will happen to the number of fish in a pond in a wooded setting if the trees surrounding the pond were cut down?" During the second session, the prospective teachers were asked to revise their original models in light of what they observed while studying a second pond in a non-wooded setting. They were then asked to use their revised model to answer a new driving question of their own choosing. A detailed description of the modeling module is found in Chapter 3 of this thesis.

### 5.4.1 Jackie and Marvin

<u>**1st Modeling Session**</u>

Jackie and Marvin constructed their model following a "stepwise" pattern characterized by creating all objects first, then defining variables for those objects, and finally, building relationships among those variables. The stepwise pattern is clearly seen during the first 35 episodes in the process map in Figure 5.9. The episode number is



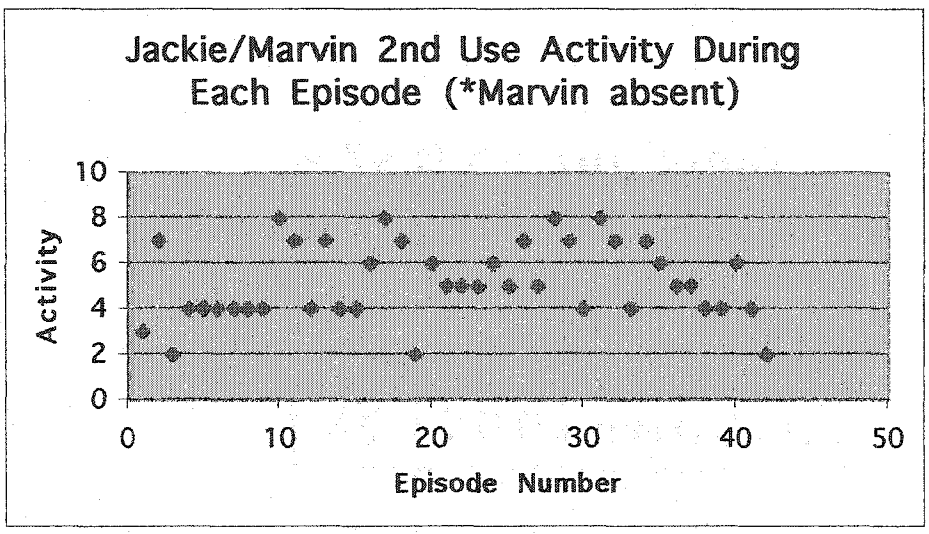

**Activity Designations**
8 - create object
7 - defined variable
6 - built relationship
5 - tested model
4 - revised model
3 - discussion
2 - questioned instructor
1 - other

*Figure 5.9* **Process Map of Jackie and Marvin's First Use of Model-It** displayed on the horizontal access of the graph, and the activity in which they were engaged on the vertical access (see Chapter 4 for a detailed account of how the process maps were generated). Jackie and Marvin did not appear to be focused on the driving question for most of the session as evidenced by the fact that they failed to create a "fish" object. They spent quite a bit of time discussing how different variables might be related. This can be seen on the process map in the numerous episodes identified as Number 3.

Jackie and Marvin did not take advantage of the computing power of the software to manage and track the variations in multiple, interconnected variables. The only testing they did during this session was among pairs of variables that were directly connected. In other words, they tested relationships they had previously built that contained no interconnectedness with other variables. For example, during episode 19 they built a relationship between a variable they defined as deciduous trees and a variable they defined as the amount of newts. When building this relationship they defined the rate of the relationship so that as the number of deciduous trees was increased, the number of newts would increase by about the same number (therefore decreasing the number of deciduous trees would result in a decrease in the number of newts). They then set up the model for a test in which they varied the number of deciduous trees and monitored the number of newts. This kind of testing would not provide any insight into the behavior of the model since they merely tested a single relationship they had built.

**2nd Modeling Session**

Jackie had to work alone during the second modeling session because Marvin was absent from class. In contrast to the first modeling session, Figure 5.10 shows that there




**Activity Designations**

8 - create object
7 - defined variable
6 - built relationship
5 - tested model
4 - revised model
3 - discussion
2 - questioned instructor
1 - other

*Figure 5.10* **Process Map of Jackie and Marvin's Second Use of Model-It**

was no pattern of creating objects, defining variables, and building relationships because this session involved revising the model. Early in the session Jackie deleted a number of variables and objects. There are a series of number 4s during the first 10 episodes displayed on the process map in Figure 5.10 that display these deletions. Some of the deleted variables were not involved in relationships, others were.

Through conversations with the owners of the ponds, the class learned that the pH of the two ponds was likely different due to the source of the water in each pond. The first pond was spring fed. The second pond was fed from run-off and had a pH similar to the fields above it. Jackie appeared to be trying to capture this in her revised model. She did some testing of her model. The testing was similar to the kind of testing she and Marvin had done during the first modeling session where only variables that were connected directly to one another were tested. It was impossible to tell if she was pleased or displeased with the results since there was no audio. There should not have been any surprises in her results based on the tests she did. She eventually connected the new "run-off' portion of her model to bluegills. She also added dissolved oxygen as a variable and connected that to the model.

**What Was Revealed**

One important revelation was that Jackie and Marvin chose not to include an important variable because, during our pond study, we had not actually measured that variable. During Episode 8 of Session 1, they chose not to include dissolved oxygen in their model. Dissolved oxygen in a pond is a critical variable associated with the pond. The computer probe we took to the pond was not functioning properly, which resulted in our not having dissolved oxygen measurements for the ponds. Jackie and Marvin's decision is interesting since it suggests that if we did not know how something was related to other things in the pond, it should not be included in the model.

In a related episode, Marvin demonstrated his frustration about not knowing certain relationships associated with the pond. He wanted data upon which to base the relationships:

> M: What I don't understand, it's tied into what Matt said . . . where is the data at? That's what I want to see when we get to the relationship thing. I don't have any data to base these relationships on . . . I don't even know . . . I'm only making these relationships because what I know about ponds and my own background . . . just personal experiences playing around in a pond as a kid. I don't have empirical . . . I'm just using intuition of what I've read and watched on TV . . . stuff like that. (Jackie/Marvin, first use of Model-It 4/11/02, episode 23)

He failed to recognize that models are often built from indirect observation of the target. Getting a model to generate data similar to what can be observed of the target phenomenon can result in figuring out the underlying mechanisms that result or resulted in the observed event or events. When the model is compared to the behavior of the actual target, similarities in behavior may suggest that the modeler's thinking is correct. Marvin continued to question the connection between data about the target and relationships among variables in Episodes 27 and 31 of Session 1:

M: Right, that's what I was just saying. We have nothing for pH. We could make something up. See, this is where you need data. Why are we coming up with these cause and effect relationships? What are we basing it on?
J: Well, it's based on the information we found out when we went to the pond.
M: I didn't . . . I have no idea why there's so many newts in the pond . . . I have no idea.
J: Well, that's what we're testing . . . .
M: Yeah, that's what I'm saying, we need more data. I mean how do we know . . . you mentioned about the newts and the trees. You didn't get that from going out that day.
J: No, I looked that up.
M: You knew that from some previous experience you had somewhere . . . all right, well, let's test some things and see. (Jackie/Marvin, first use of Model-It 4/11/02, episode 27)

M: It's because we set it up that way, we knew ahead of time what the relationship was. It's not telling us something we didn't know.
J: I know.
M: We told it to do that.
J: Yeah, that's what this whole thing.
M: Yeah, but where are we getting new knowledge from?
J: I don't know.
M: That's the question we had before . . . you have to have the data to do this model to know what the relationships are. (Jackie/Marvin, first use of Model-It 4/11/02, episode 31)

Finally, Jackie and Marvin based their prediction about what would happen to the fish in the pond on a questionable rationale and dubious test results from their model.

Near the end of the first session, after the class was informed that they had two minutes to complete their modeling for this session, Jackie and Marvin decided to report that the fish at the pond (an object they had not built into the model) would behave just like the newts (an object they had built into the model):

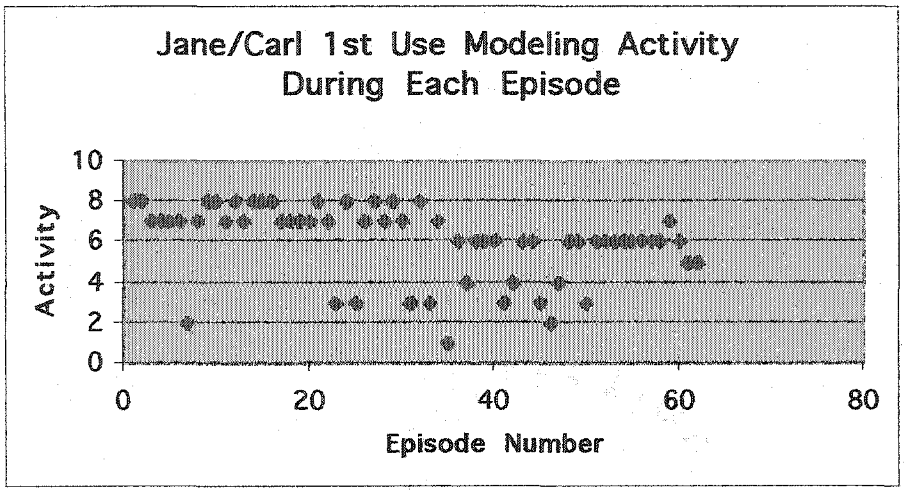
> M: OK, did we do our driving question?
>
> J: Well, he said to only work on it for a couple more minutes because I think we're going to come together as a group and share our predictions and the question was what happens to the fish if we cut down the trees . . . but it will basically be the same thing as the newts.
>
> M: It's going to be the same thing as the newts.
>
> J: You still have newts if you cut down trees. It was just the number decreased, so you're still going to have fish if you cut down the trees just in a smaller amount.
>
> M: Okay, I buy that . . . yeah, not only that because aren't those trees down 50 yards from the pond, but those newts need to go to those trees . . . they'll find that pond somehow . . . like the saying goes, life finds a way of surviving. If they have to go a little farther, it will decrease the newts, but they'll still be some newts if there's going to be trees around.
>
> J: I mean we're supposed to solve it for fish, but it's going to be the same thing (inaudible).
>
> M: Oh, yeah, we were supposed to solve it for fish weren't we?
>
> J: But that was a relationship that I knew . . . but I think that it is going to be the same thing.
>
> M: Like the same principles . . . I mean fish might be a little more sensitive, but I think it is a good indicator of the direction. Either way, the health of the pond is what the bottom line is. 'Cause I'm looking at this now, the initial premise or driving question's different, but I'm looking at it more from an environmental type . . . he could just as easily have said, we want to check the health of the pond today and then we're going to cut the trees down and see what the health of the pond is . . . the definition of health would be the number of newts, the number of fish, things like that, the pH of the water, temperature, the turbidity. I think we would be looking at the same thing. So he had to put all of these. He had to save all this, punch all this information in, set this all up before we could even do this. Okay. (Jackie/Marvin, first use of Model-It 4/11/02, episode 48)

Marvin and Jackie concluded that reducing the number of trees would negatively impact the number of newts and assumed that the newts and fish would be similarly affected by variables associated with the pond. The object fish was not part of their model. This is akin to suggesting that everyone "minds the heat and humidity" of summer the same way. In addition, the only tests they conducted of their model, as mentioned above, were of variables that were connected directly to one another, and therefore they were not taking advantage of the power of the software.

### 5.4.2 Jane and Carl

#### 1st Modeling Session

Jane and Carl constructed their model following an "alternating" pattern characterized by creating an object and then identifying variables for that object before moving on to creating new objects. This pattern is clearly seen during the first 35+ episodes in Figure 5.11 below. Once they had objects and variables defined, they built relationships among those variables. It took most of the entire session for them to create their objects, define their variables, and build relationships among those variables. It did not seem that the driving question was guiding their modeling efforts since they did not refer to the driving question until near the end of the session. They created the important variable "number of trees" while the entire class was engaged in a discussion about their findings from the first modeling session.




**Activity Designations**

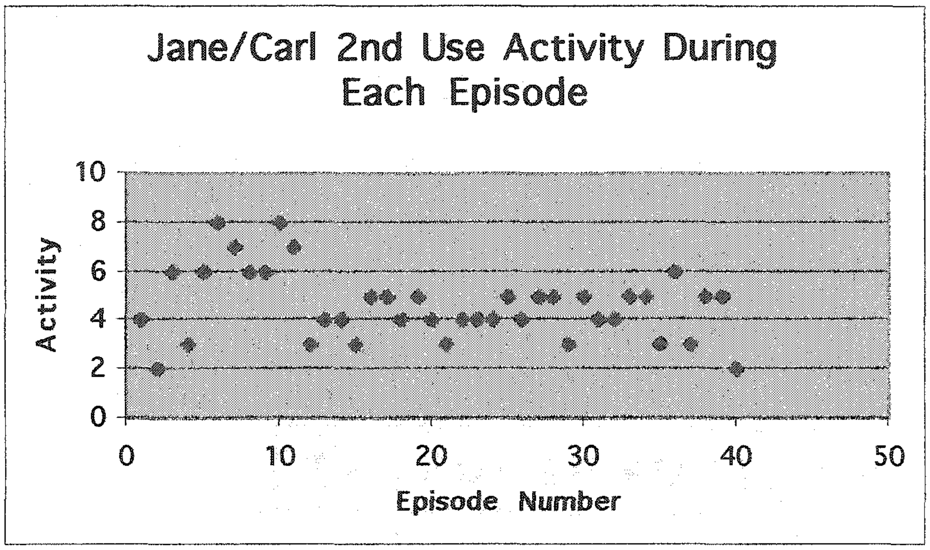
8 - create object
7 - defined variable
6 - built relationship
5 - tested model
4 - revised model
3 - discussion
2 - questioned instructor
1 - other

*Figure 5.11* **Process Map of Jane and Carl's First Use of Model-It**

Jane and Carl did very little testing of their model and only just at the end of the session, and again during the discussion at the end of class. As a matter of fact, one of the two test runs that they set up was never actually run. In the only test they completed, they varied the number of trees and measured the number of bluegills (this is the driving question).

**2nd Modeling Experience with Model-It**

The "alternating" pattern apparent in the first modeling session was not evident during the second modeling session as seen in Figure 5.12. Instead, Jane and Carl spent most of this session alternately testing and revising their model. For example, at the very beginning of the session, they changed the rate of the relationship between the number of trees and the pond temperature. This revision was based on data we collected at the two ponds that suggested that there was little difference in the temperature of the two ponds even though the amount of shade at both ponds was presumed to be different. They also eliminated the variable dissolved oxygen in the pond inexplicably. That variable was




**Activity Designations**

8 - create object
7 - defined variable
6 - built relationship
5 - tested model
4 - revised model
3 - discussion
2 - questioned instructor
1 - other

*Figure 5.12* **Process Map of Jane and Carl's Second Use of Model-It**

involved in five relationships. Unfortunately, there was little discussion of that episode, so little can be determined about their reasons for this revision:

J: What do you want to get rid of?
C: Like dissolved oxygen.
J: We would have to go to . . . how do we do that?
C: I don't know. (Jane and Carl, second use of Model-It 4/18/02, episode 22)

Throughout the session Jane and Carl had a difficult time identifying a question to pursue. The revisions they made early on in the session resulted in two unconnected models, each consisting of elements from the model they built during the first modeling session. One of these two became the focus of the second session. It appeared as if they were attempting to create a model that would show predator/prey relationships involving bluegills, minnows, and dragonfly nymphs. They encountered difficulties in doing this. The way they had built the relationships in their model resulted in the number of bluegills, minnows, and nymphs each being dependent variables. Therefore, they could not vary any of those variables to see what might happen while testing the model. In order to be able to run/test the model, they had to identify an independent variable. They chose pH, a quantity that varies throughout each day and on average throughout the year. Unfortunately, they were not pursuing this aspect of pH (its daily or diurnal variation), nor did their model allow for this aspect of pH. They also seemed to be confused about how Model-It works. Jane and Carl conducted more tests in this session than they had during the first modeling session. On a number of occasions, they ran the model but did not vary anything. They appeared to wait expectantly for something to happen. It was as if they expected it, since they built a relationship saying that minnows and nymphs would vary directly with bluegills (based on the assumption that bluegills eat nymphs and minnows) and that the amounts of each of those prey species would automatically decrease when they ran the model. Much of the second half of this session was spent trying to work out this apparent problem, but it was only at the end of the session that they asked for clarification.

**What Was Revealed**

One important revelation was that Jane and Carl chose not to include certain variables in their model because they were unsure of the role of those variables in the ecosystem. For instance, in the following excerpt they considered the impact of cutting down the trees on the composition of air around the pond:

C: What can we do for air?

J: I guess temperature of the air.
C: Yeah.
J: We didn't read what that was. It was cold.
C: It was probably about 40°.
J: With air what else did we do?
C: It's like $CO_2$ or $O_2$.
J: Do we want to get into that since we don't know what it is?
C: Umm . . . probably not. (Jane and Carl, first use of Model-It, 4/11/02, episode 8)

The excerpt from Episode 8 also suggests that Jane and Carl may have had misconceptions about the effects of photosynthesis and respiration of the trees on the composition of air. Any $CO_2$ or $O_2$ produced by trees diffuses immediately into the atmosphere. Also, the atmosphere is extremely vast and not likely to be greatly affected by the respiration and photosynthesis of a relatively small number of trees.

Another revelation, related to the decision to exclude relationships of which they were unsure, centered on the Model-It software. Jane expressed frustration during both modeling sessions over the choices provided by the Model-It software for defining the rate of relationships. Semi-quantitative descriptors such as "increases by the same amount" or " decreases by more and more" can be limiting if a modeler believes that the relationship between two variables exists in a different way. For example, Jane and Carl wanted to their model to behave so that there would be a positive, linear relationship between dissolved oxygen and minnows until the dissolved oxygen reached some value, after which the minnow population would remain constant even if dissolved oxygen were to be increased beyond that value:

Instr.: So, you don't think there is a relationship between dissolved oxygen and minnows.
J: Well, there is but it's not.

C: It can't be expressed.
J: . . . with these words . . . is there any way we can? (Jane and Carl, first use of Model-It, 4/11/02, episode 8)

There were additional issues associated with the Model-It software that were revealed in the process-video data. For example, Jane and Carl were attempting to model predator/prey relationships during the second modeling session. Such relationships are difficult to model with Model-It. The ease of use of the software in some instances results in limitations in modeling capabilities. At the time of the study, Model-It did not permit cyclic relationships. For instance, a modeler might want to build relationships so that the number of prey is affected by the number of predators. In turn, the number of prey affects the number of predators. As lynx eat hare, there become fewer hare to eat which in turn affects the number of lynx. Jane and Carl ran into difficulties when trying to build relationships among bluegills, minnows, and dragonfly nymphs.

Jane and Carl also revealed that they were not completely proficient with the operation of the software. As discussed briefly above, a failure to understand how the Model-It software operated in "Test" mode resulted in Jane and Carl spending a considerable amount of time trying to achieve desired results. They built relationships and set up to test two or more variables. They clicked on the run button and expected the model to behave as if time was passing and the variables were changing naturally. They did not appear to understand that the user has to vary the independent variable to see changes in the dependent variables.

C: They like kept going down but they're not dying.
J: They should definitely be dying. Our minnows are not dying the way they're supposed to be.

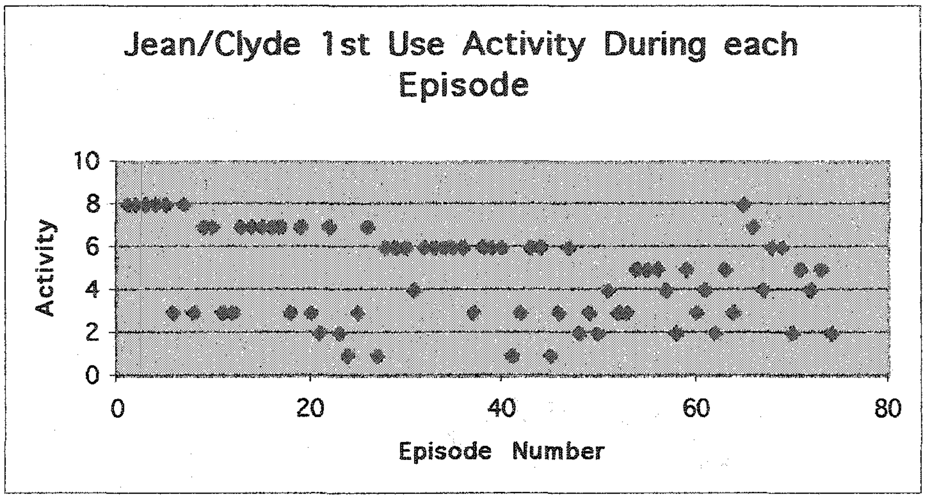
C: We can't even get stuff to die right on ours.
J: Apparently the bluegills aren't eating them as much as they're supposed to be. (Jane and Carl, second use of Model-It, 4/18/02, episode 27)

Jane and Carl kept trying to change the initial conditions of the variables they were testing in the hope of getting the model to behave, as they desired. Unfortunately variables do not change "automatically" in Model-It. The user must change one variable in order to prompt changes in others. Eventually Jane and Carl asked the instructors for help (Episode 40, the last episode of the second session).

### 5.4.3 Jean and Clyde

**1st Modeling Session**

Jean and Clyde defined numerous objects and variables following the "stepwise" pattern of defining all objects first, then defining variables for those objects. This pattern is clearly seen during the first 25+ episodes in Figure 5.13. After all objects and variables were defined, they rearranged them on the screen (Episode 24) and then built relationships among the variables. Jean and Clyde appeared focused on the driving question as evidenced by their early inclusion of variables describing the amount of sunlight on the pond and the number of trees and fish. They ran numerous tests of their model. The tests prompted them to make revisions via the addition and subtraction of objects, variables, and relationships and changing the rates of certain relationships.




**Activity Designations**

8 - create object
7 - defined variable
6 - built relationship
5 - tested model
4 - revised model
3 - discussion
2 - questioned instructor
1 - other

*Figure 5.13* **Process Map of Jean and Clyde's First Use of Model-It**

**2nd Modeling Session**

The stepwise pattern was not evident during the second modeling session. Instead, Figure 5. 14 shows that most of the time during the second session was spent testing and revising the model. Jean and Clyde had a difficult time identifying a driving question with which to answer with their model. They attempted to examine predator/prey relationships among fish and minnows but soon found that Model-It does not permit cyclic relationships:

C: It says we can't have a cycle . . . can't have it back and forth.
J: Oh, well, that solves our problem . . . it's probably assumed . . . it must be assumed . . . I don't know.
C: Well, it will work either way . . . .
J: Yeah.
C: Do we want to change what we have? Do we want to make it . . .
J: Go the other way . . . .
C: Do we want to make it go the other way? 'Cause that's what we know . . . .
J: Yeah . . . .

C: Okay . . . delete . . . decreases a lot . . . (types). (Jean and Clyde, second use of Model-It, 4/11/02, episode 11)

We found out from our field study that the pH of the two ponds was different perhaps due to the source of the water in each pond. The first pond was spring fed. The second pond is fed from run-off and had a pH similar to the fields above it. Based on this information, Jean and Clyde added an object and variable related to pH of the water source (they

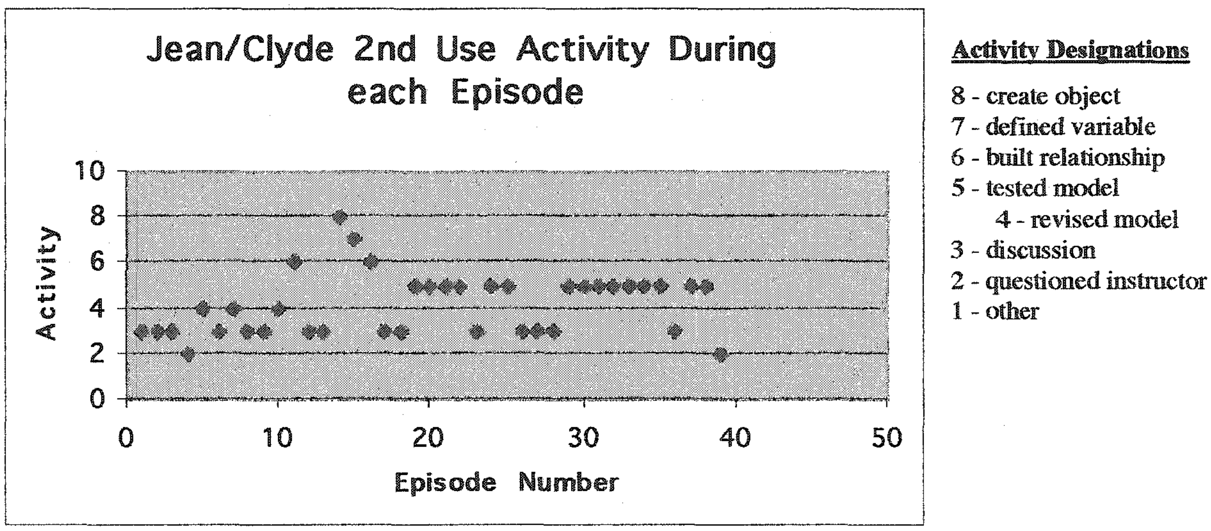



*Figure 5.14* **Process Map of Jean and Clyde's First Use of Model-It**

called it run-off pH). They did not end up using this in any testing of the model.

Throughout the session, they struggled to identify a driving question (see Figure 5.14, Episodes 13, 18, 23, 26). For example:

C: … I can't think of a way to incorporate
J: me neither… why don't we just do… let's think of our question… what was yours? Were you thinking of one with the pH?
C: I'm not sure…anything I was thinking about was lost… um,
J: it doesn't matter, there's no right or wrong… whatever we want… we could say that temperature changes drastically or the… there's

a… the number of trees totally… there was a hurricane and all if the trees were totally lost… it doesn't matter… pH…
C: the only variable we're given to start with is the number of trees…
J: So (inaudible)
C: So, that changes everything else… I thinking of how we're going to work with this… Oh wait, wait… this is dependent, everything's dependent
J: it doesn't matter
C: No, I'm just trying to get an idea (Jean and Clyde, second use of Model-It 4/18/02, episode 18)

Eventually they returned to the original driving question and attempted to vary the temperature of the pond by changing the amount of sunlight that fell on the pond. This time they attempted to drastically change the temperature of the pond. Jean and Clyde conducted a number of tests during this modeling session. However, they conducted a number of iterations of essentially the same test, the only difference being that they monitored additional variables with each subsequent test run. They did not revise anything based on any of their tests.

**What Was Revealed**

One important revelation was that Jean and Clyde engaged in conversations related to the nature of models and modeling. In each instance, these conversations involved the instructor. For example, they were concerned that they were deciding on the relationships being built in some instances where they were unsure. The instructor explained that this is an aspect of the nature of scientific modeling. Clyde appeared to understand the clarification:

C: My only problem is that if you build it into the model it's going to be based on like the . . . .
J: Increase, decrease.

C: It's going to be things that I input, so I can either make it affect it or not make it affect it.
Instr: Right, but that's the nature of . . . .
C: That's the point of the model, okay. (Jean and Clyde, first use of Model-It 4/11/02, episode 21)

Later a question addressed to the instructor resulted in direct instruction regarding the relationship between the behavior of the target and model and changing models:

J: Once we find a relationship and once we run it . . . are we done then or do we adjust?
Instr: I don't know. Did it turn out the way you think it should turn out?
C: No.
Instr: Okay, then you want to tweak your model.
C: Ours basically said that the lower the number of trees the more fish there would be.
J: That makes sense though because we thought that we had cold water fish.
C: Yeah.
J: But they're warm water fish so . . . .
C: But there's a threshold.
J: Right.
C: I just changed this.
Instr: So now you can test it . . . when you get your model . . . I mean again, now what we can do . . . what we're going to do is go to a second pond. So now we can see what our model predicts . . . now granted it's a different pond. This is the thing, when your model agrees with reality, it doesn't necessarily mean but it has given you some insight. You may now have a theory as to why something goes the way it goes. It may not be true. What else can it predict? (Jean and Clyde, first use of Model-It 4/11/02, episode 58)

In another instance, the instructor explained how new evidence would result in changing a model:

J: Mike, I have a question, you know how he said made all the fish in the lower pond die?
Instr: Yup.

J: That's something that has nothing to do with any of the factors we're dealing with. So . . . .
C: So, that might be causing it without thought of anything else.
J: The reason that there's not fish doesn't have anything to do with . . . .
Instr: Right, but the fish don't have to be the part of the pond that you're exploring.
J: Okay, to just . . . .
Instr: You can get your pond operating the way you want it to . . . the way I'm seeing it is . . . model that lower pond right now to me would have lots of macroinvertebrates around . . . maybe you want to re-introduce the bluegills and see what happens . . . I'm just saying the fish do not have to be the focus of your research question.
J: I know we had to adjust it cause it was something we didn't know.
Instr: Right, correct, that would be something that happens, as scientists gain new information, we didn't know that, and that impacts my model, so I have to change it and now I can move forward . . . you're not abandoning it. (Jean and Clyde, second use of Model-It 4/18/02, episode 4)

Another important revelation was that Jean and Clyde appeared to possess some misconceptions about pond ecosystems. For instance, during Episode 30 of the first session, they created relationships between the number of trees and the amount of $CO_2$ and $O_2$ in the air. Prior to building the relationship, Clyde explained his rationale:

C: The number of trees . . . because the less trees there are the more $CO_2$. (Jean and Clyde, first use of Model-It 4/11/02, episode 21)

Any $CO_2$ or $O_2$ produced by trees diffuses into the atmosphere immediately. The atmosphere is extremely vast and not likely to be greatly affected by the respiration and photosynthesis on a relatively small number of trees. They also created relationships between trees and the amount of $CO_2$ and $O_2$ in the pond. Daily or diurnal variations of $CO_2$ and $O_2$ exist in a pond but those variations are the result of life cycles in the pond. Trees around the pond would not influence the amount of $CO_2$ and $O_2$ in the water directly. Trees could, however, affect the amount of sunlight falling on the pond which, in turn, could affect factors in the pond that do serve to regulated the amount of those gases dissolved in the pond. Clyde knew that the pH of a pond varies throughout the day due to fluctuations in the CO2 in the pond. Nevertheless, he did not appear to know that plant photosynthesis and respiration as well as the decomposition of algae cause those fluctuations.

It was also revealed that Jean and Clyde chose to neglect certain variables and relationships of which they were unsure. For example, they chose to eliminate a relationship they had initially built between fish and dissolved oxygen:

J: For right now, it makes sense that it wouldn't affect if it's more.
C: Yeah, I mean.
J: You'd rather have more than not enough. . . I mean, maybe not but that's more logical.
C: Yeah, that's like saying humans can live on pure oxygen but we're used to breathing like 20% so . . . so this one . . . at least . . . I don't know if this one's even logical anymore.
J: As the pond DO increases . . . should we just get rid of that one?
C: That's what I'm thinking . . . . Okay, is there anything else that we missed? (Jean and Clyde, first use of Model-It 4/11/02, episode 52)

Here, Jean suggests they not include a relationship between the plants in the pond and the dissolved oxygen in the pond:

J: I don't know . . . it seemed to be with more plants there seemed to be more life, you know what I mean? So maybe that the life would use up the difference so there wouldn't be an increase because . . .
C: It would be proportional to life so . . . it would basically remain constant.
J: Yeah, but I don't know . . . I don't have any idea . . . so we can just not even do this thing.
C: I don't want to rule out (inaudible) it's just . . . .
J: It's hard with the drought thing . . . .
C: Yeah, that does make it difficult . . . if that didn't happen, then we would know for sure but since an outside factor that we . . . I can't

> think of a way to incorporate. (Jean and Clyde, second use of Model-It 4/18/02, episode17)

Finally, Jean and Clyde experienced some difficulties with the software when they found they were not permitted to create cyclic relationships. In addition, Jean appeared to be unsure if relationships they built were still operating when the model was being run, even if those relationships had not been selected to be monitored (graphed). Clyde attempted to clarify this:

> J: So we can just make a question up and alter one of these and see what happens… to the whole picture. . . . do you know how to run it . . . to make everything change . . . is that what we have to do . . . I don't know . . . he just said, think of a question and then change it and then run it . . .
> C: Um . . . .
> J: 'Cause right here we were testing two at a time.
> C: Well, it's not . . . but that's not necessarily . . . whenever we're starting with the trees, the trees are altering exposure, and carbon dioxide, and oxygen and so you're altering these three things . . .
> J: So we can't do everything . . . obviously not.
> C: I mean if you want to check everything you can go like . . . you can bring up one of these, this, this, this . . . . (Jean and Clyde, second use of Model-It 4/18/02, episode 26)

### 5.4.4 Kate and Matt

**1st Modeling Experience With Model-It**

Kate and Matt defined numerous objects and variables following the "stepwise" pattern of defining all objects first, then defining variables for those objects. This pattern is clearly seen during the first 15+ episodes in Figure 5.15 below. After all objects and variables were defined, they built relationships among the variables. Kate and Matt appeared to be focused on the driving question. They tested their model for the first time after creating just two relationships. From that point on they tested their model frequently. An "iterative" pattern of building, testing, revising, and testing again can be seen in Figure 5.15 beginning with Episode 19 and continuing throughout the rest of the

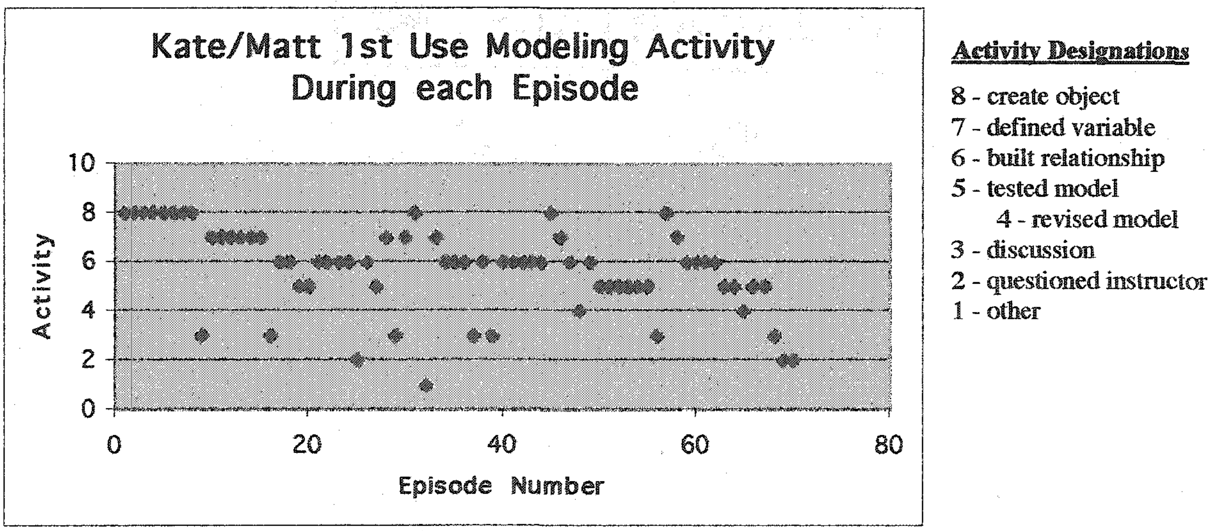



*Figure 5.15* **Process Map of Kate and Matt's First Use of Model-It**

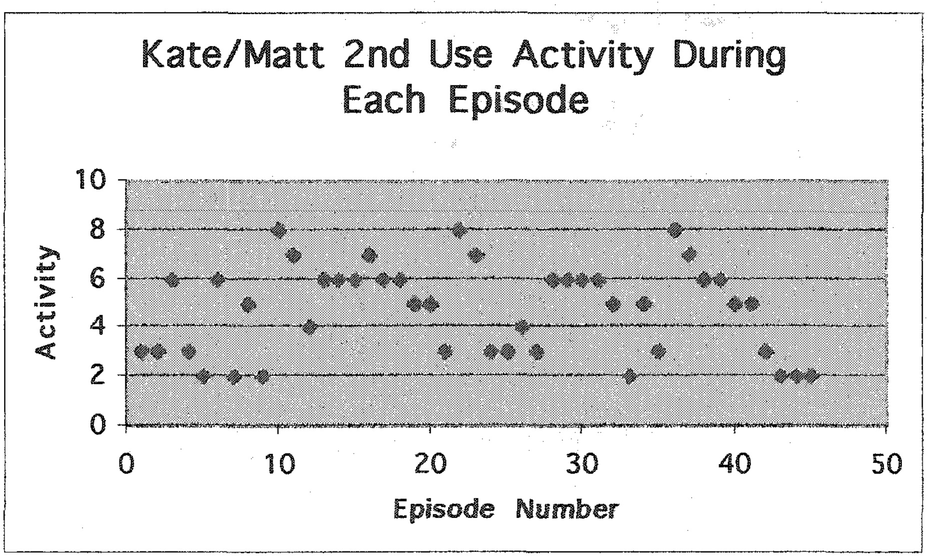
session. The revisions included adding and deleting objects, variables, and relationships as well as changing the rates of certain relationships.

Matt and Kate also ran a test during the first modeling session in which they attempted to internally validate their model (Episode 66). They created a series of relationships involving bluegills. They had previously created a similar series of relationships involving newts. They tested both to assure themselves that both were behaving similarly.

**2nd Modeling Experience with Model-It**

The iterative pattern evident in the second half of the first modeling session was also apparent for much of the second session as seen in Figure 5.16 below. Kate and Matt made significant revisions to their original model. They concentrated on and revised part of the original model and did not use the other part at all, so the resulting model consisted of two separate models. The two parts were connected by certain relationships but those relationships did not impact the behavior of the components of the model they tested. Kate and Matt appeared to focus on the question, "What would happen to the biodiversity of the pond if the bluegill population was increased?" The second pond we visited had a considerably higher biodiversity than the first. After speaking to the owner's of the ponds it was revealed that the second pond likely did not have any bluegills in it due to a drought. Kate and Matt no doubt wanted to get their model to generate similar results.

Kate and Matt defined a variable for the pond called "biodiversity" and built an inverse relationship between it and the bluegills. As such, the biodiversity was automatically going to be affected by the presence of the bluegill. In our field study of the pond, we collected samples of organisms and calculated an index for biodiversity. It is no wonder the model behaved as it did. Later, they added bass to the model, who would prey on the bluegills and to a lesser extent macroinvertebrates, thus adding to the biodiversity in one sense and detracting from it in another. They described the rates of the relationships so that the bass preyed heavily on the bluegills and to a lesser extent on macroinvertebrates. Kate and Matt were pleased to see the positive effect that adding a large predator had on the ecosystem. Finally, they added a fisherman to see what effect humankind would have on the ecosystem; assuming the fisherman would be catching bass.




**Activity Designations**

8 - create object
7 - defined variable
6 - built relationship
5 - tested model
4 - revised model
3 - discussion
2 - questioned instructor
1 - other

*Figure 5.16* **Process Map of Kate and Matt's Second Use of Model-It**

**What Was Revealed**

One important revelation was that Kate and Matt engaged in conversations related to the nature of models and modeling. They expressed concern that they were answering the questions they had about the pond ecosystem before running their model because they were telling the model how to behave. The following excerpts demonstrate their concern:

M: What's the burning question then?
K: Do we need one?
M: Yeah, is biodiversity directly related to bluegill population?
K: Yeah, 'cause we just made it like that.
M: Or more so from pH?
K: We can't . . . we should be able to do this, but we can't because these relationships are whatever we make them.
M: True . . . so we answered our own question before we even ran the . . . .
K: We wrote the answer to our question . . . (Kate and Matt, second use of Model-It, 4/18/02, episode 21)

M: I don't know how we might go out and test this except I might go out there with a fishing rod and catch some bass.
K: I guess adding a bass would only affect it if there is a high bluegill population.
M: The inherent problem with this is we have answered . . . we always answer our question before we come up with it . . . we're designing the relationship the way we want it to work, so I guess we go out and we test it.
Instr2: Can you build a relationship about what we know about what we saw out there
K: I mean we're doing that too . . . .
Instr2: And then say, okay, we know that bass are predators and we know that bass eat sunfish, let's form a hypothesis . . . you can form a hypothesis and then run it and see what happens . . . that's one way you can look at this. This is to show you how complex something like this is. (Kate and Matt, second use of Model-It, 4/18/02, episode 44)

Matt recognized, according to the second passage above, that the way to truly test their model is to "take it out and test it," meaning that they need to make observations of the target system and compare the behavior of the model and target. Kate and Matt discussed how they might test their predictions in the field but again. Matt actually appeared frustrated by the fact that a model behaves as the modeler tells it to:

K: Well we have to introduce bluegill to the lower pond and see if the biodiversity goes down and then add bass to see if it goes back up.

Because if the bass are eating just as much macroinvertebrates as the blue gills then it will all be . . . .

Instr2: The size of the fish determines what their prey species are going to be.

K: I'm thinking bass is a bigger fish and it's not going to want to eat the macroinvertebrates, but I guess when they're little they would still eat them . . . maybe if you added just big bass that don't reproduce . . . just sterile predator fish, that would increase biodiversity . . . but not necessarily the reproductive fish.

Instr2: What would happen if you added bass and took the bluegill out . . . what would happen to the population of the macroinvertebrates?

K: Oh, it would stay low . . . because the bass would have to eat them because they couldn't eat the blue gill.

Instr2: Can you break the model and take the bluegill out . . . and make that work?

K: I don't know.

M: We can manipulate it to do whatever we want it to . . . that's what I was just saying.

K: If we would take the blue gill out, then we would just be deleting a relationship.

M: We answer our questions before we ask them.

K: Like a direct relationship between the bass and biodiversity, and we create the relationship so we can't model the relationship after we just created it . . . you know what I mean. (Kate and Matt, second use of Model-It, 4/18/02, episode 45)

There was another revelation related to the software. Matt and Kate encountered difficulty when trying to model predator/prey relationships due to the software not permitting cyclic relationships. In addition, Matt appeared to be confused by the operation of the software in "test" mode. He was unsure if all of the relationships in the model were still actively working, even if they were not being monitored during a test run:

M: But is it testing those variables right now?

K: Yeah, they're all connected.

M: Are you sure? But when you do this graph simulation, is it measuring anything that isn't up?

K: It has to.

M: Hear what I'm saying though? Does it show other variables?
K: I think it's including every relationship we put in there.
M: Let's try it one time . . . Okay, okay . . . I see what you're saying because you can't really plug in more boxes.
K: I mean when we did a tree, when we affect the trees we're affecting the water temperature. (Kate and Matt, first use of Model-It, 4/11/02, episode 63)

Finally, it was revealed that Kate and Matt possessed sophisticated knowledge of pond ecosystems. The following excerpt demonstrates this:

K: I need to move this . . . it probably wouldn't make a difference to the plants.
M: The dissolved oxygen?
K: Yeah
M: I can't imagine . . . since they're . . .
K: They're making it.
M: They're making it.
K: Oh, but would their health . . .
M: With sunlight.
K: Affect the dissolved oxygen?
M: Would it raise the dissolved oxygen?
M: I know that due to algal blooms the dissolved oxygen goes down because the plant life is shut off because they cut off the sunlight . . . so, yeah, the more plants the higher the dissolved oxygen . . . that makes sense.
K: So algae is a plant?
M: It's a protist . . . it's a photosynthetic protist . . . kind of a single-celled, but it can be multi-cellular. But they consider them protists . . . and . . . .
K: So are they using oxygen?
M: Oh, yeah, oh . . . no, no, no, no, they create oxygen as well . . . they are plant life.
K: Well, why don't they increase dissolved oxygen in the pond then?
M: Because they cut off the plant life and they're on the surface so . . .
K: I remember reading . . .
M: I think the oxygen they give off kinda goes right into the air.
K: Okay.
M: Whereas the plants that are submergents and emergents, they're kind of bubbling oxygen into the water . . . I don't know exactly

why that works . . . but I read it I think somewhere that the dissolved oxygen goes down after algal blooms.
K: So this one's gonna decrease?
M: Right. (Kate and Matt, first use of Model-It, 4/11/02, episode 31-33)

### 5.5 Summary

In this chapter I have presented the results of my analysis. In the next chapter I discuss the results in light of existing literature and make assertions related to each research question I have posed.

# Chapter 6

# DISCUSSION

In this chapter I will present a discussion of the results of my analysis in light of the existing literature on scientific models and modeling in science education. Each of the three research questions will be addressed in turn followed by a discussion of the interplay among the three questions.

## 6.1 Discussion of the Prospective Teachers' Understandings of the Role of Models and Modeling in Science

In this section I will address the first of my research questions, "*What are prospective science teachers' understandings of scientific models and modeling, and in what ways do they change during modeling tasks that include building and testing computer models of pond ecosystems?*" The results of my analysis add depth to the limited research on prospective science teachers' understandings of the role of models and modeling in science. These results both confirm and extend findings reported in the literature. This study is unique in that I also examined changes in the prospective teachers' understandings. I will begin by making four assertions. Next I will discuss the general trends in the prospective teachers pre- and post-module understandings followed by a discussion of the more specific changes in each of the five dimensions of modeling: purposes of models, building models, changing models, multiple models, and validating models. Finally, I will present a comparison between the pre/post-module understandings of the prospective teachers in this study and those of pre-college students found in the literature.

### 6.1.1 Assertions for Research Question #1

In this section I make four assertions regarding the prospective teachers' modeling understandings of scientific models and modeling, and how they changed during modeling tasks that included building and testing computer models of pond ecosystems: 1) most of the prospective science teachers' held naïve pre-module understandings about the role of models and modeling in science; 2) the dimensions of modeling understanding are tightly coupled and therefore it is unlikely for a prospective teacher to have naïve understandings in one dimension and scientific views in another; 3) it is possible in a short amount of time to enhance prospective teachers' modeling understandings in small graduations; and 4) prospective teachers' ideas about models and modeling appear to be bounded by the context.

**The bleak state of existing views**

From the results of my analysis one could construe the state of affairs of preservice teachers to be particularly bleak, related to teachers' knowledge of the nature of scientific inquiry, including how scientists use models and modeling in their work. Most of the prospective science teachers' held naïve pre-module understandings about the role of models and modeling in science. These results are similar to those reported in the literature for studies involving preservice and inservice teachers, and pre-college students. Comparing the results of my analysis of the prospective teachers' views to existing empirical research, I conclude that the prospective science teachers had pre-module modeling understandings more similar to pre-college students than scientists. In their seminal work in this area Grosslight et al. (1991) identified three general levels of modeling understandings. They discovered that groups of pre-college students (7th and 11th graders) and experts demonstrated understandings that were characteristic of one of those levels with most 7th graders possessing level I understandings, most 11th graders possessing level II understandings, and only the experts possessing level III understandings. Prior to the module I attempted to classify the prospective teachers' understandings based on the levels identified by Grosslight et al. Through my analysis I noticed subtle, but not unimportant differences in understandings in each dimension that prompted me to devise a four-level classification system. One of the strengths of this study is in developing a finer grained analysis in order to differentiate the different dimensions of models and modeling and to gain a better understanding of the areas that are most problematic.

**Understandings across dimensions are tightly coupled**

The dimensions of modeling understanding identified from the literature appear tightly coupled to one another and therefore it is unlikely for a prospective teacher to have naïve understandings in one dimension and scientific views in another. Justi and Gilbert (2003) identified various *aspects* of modeling understandings, similar to what I have referred to as dimensions and criticized the notion of levels on the basis that it was too broad sweeping. Their findings suggested that teachers were not likely to possess understandings in only one level for all dimensions of modeling understanding. The results of the present study support Justi and Gilbert's criticism of the notion of levels to the extent that that these prospective teachers did initially possess understandings that were of differing levels depending on the dimension of modeling understanding. However, 7 out of the 8 prospective teachers held views in each dimension that were no more than one level higher or lower than any other level both prior to and after the module. Table 6.1 displays a comparison of Carl's pre/post-module views. All of

**Table 6.1**

*A comparison of Carl's the ratings of Carl's pre/post modeling understandings for each dimension*

| | pre-module understandings | | | | post-module understandings | | | |
|---|---|---|---|---|---|---|---|---|
| **DIMENSION** | 1 | 2 | 3 | 4 | 1 | 2 | 3 | 4 |
| **PURPOSE OF MODELS** | √ | | | | | | √ | |
| **BUILDING MODELS** | | √ | | | | | √ | |
| **CHANGING A MODEL** | | √ | | | | √ | | |
| **MULTIPLE MODELS FOR THE SAME THING** | | √ | | | | √ | | |
| **VALIDATING MODELS** | | √ | | | | | √ | |

Carl's pre-module views were within one level of one another as were his post-module views. The same pattern was true for six of the other seven prospective teachers. So although the notion of level, as suggested by Grosslight et al. and criticized by Justi and Gilbert may be too broad sweeping, it appears unlikely that an individual will have limited or naïve views in one dimension of modeling understandings and expert-like or scientific views in another.

**Understandings were enhanced, but in small graduations**

It is possible in a short amount of time to support small graduations in prospective teachers' modeling understandings. There was a general trend of changing from less to more scientific views of models and modeling among the eight prospective teachers who participated in the study. The changes were not dramatic but rather graduated. In light of the fact that the instructional module was relatively short in duration the changes were significant. It is impossible to state unequivocally that all of the changes in modeling understandings that were identified were a direct result of the modeling module. However, it is reasonable to assume that the module contributed to those changes. Therefore I conclude that activities including building and testing models, field study of complex phenomena, and explicit instruction *have the potential to* support prospective science teachers in developing more sophisticated understandings of the role of models and modeling in science. My analysis also suggests that while transitioning from naïve to more sophisticated understandings of the role of models and modeling in science is possible from engaging in experiences like those encountered in the modeling module, transitioning to scientific or expert-like views is more difficult. The evidence for this includes the fact that most prospective teachers who initially held naïve views failed to achieve expert-like status.

**Understanding was bounded by the context**

Most of the prospective teachers thought about models and modeling more scientifically after the module, but their understanding appeared to be bounded by the context. Most of these prospective teachers could identify scientific uses of models such as making predictions and appeared to understand that a model must be made to behave like its target. However, they were unable to transfer the notion of model-based reasoning to unobservable phenomena such as events that occurred in the distant past or that occur on a microscopic scale. One positive aspect of the instructional module is that there does appear to be a relationship between what they experienced during the module and what they did and did not appear to gain from those experiences. Their views of the purpose of models were consistent with those experiences and it is plausible that one's view of the purpose of models would influence how one imagined models to be build, tested, and changed.

For the sake of this discussion it is convenient to divide the prospective teachers into three groups based on their post-module understandings: those with scientific views (Kate and Clyde), those with nearly scientific views (Jean, Jane, Jackie, Carl, and Matt), and Marvin, whose views were inconsistent. After the module, those prospective teachers with nearly scientific views appeared to view models as tools used to explore "what if?" scenarios about a target. In most cases the investigations they envisioned could not be undertaken on the target itself for a variety of reasons, including the possibility of danger to the target or its environment, that an investigation of the actual phenomenon might take too long, or that the investigation was cost-prohibitive to undertake. Only those prospective teachers who held scientific views recognized the value of using models to develop explanations of events that took place in the distant past or on a scale that prohibits direct observation.

The essence of model-based reasoning resides in getting the model to behave like its target. Doing so can be one means for figuring out the behavior of the target. It appears that these prospective teachers recognized the importance of *the process of getting the model to behave like the system being modeled* but did not recognize *that process* as the point of building the model in the first place. The issue therefore becomes one of transfer, that is, allowing one to apply what has been learned in new or different situations (Bransford et al., 2000). A "what if?" scenario is exactly what we examined during the module. Our driving question, "What will happen to the fish in a pond in a wooded setting if you cut down the trees around the pond?" was a "what if?" scenario. The prospective teachers, again I refer to the five prospective teachers who had similar, nearly scientific views, did not place much emphasis on the importance of a model to examine such "what if?" scenarios. This is of great importance because models play a critical role in the development of explanations of unexplained natural phenomena. It is only after a model *is behaving* like its target that it can be used to make predictions about how a system *mightl behave* under different conditions. The prospective teachers were unable to transfer what they learned about models and modeling from examining a "what if?" scenario of a readily observable phenomenon to phenomena that are not readily observable such as events in the distant past or those that cannot be directly observed.

### 6.1.2 General Trends in the Prospective Teachers' Pre/Post Modeling Understandings

There was a general trend across the eight participants of changing from less to more scientific views of models and modeling. Unfortunately none of the prospective teachers made huge leaps. Most of the positive changes (≅78%) were from one level to the next and generally from Level 1 to Level 2 or Level 2 to Level 3. It would appear therefore that those prospective teachers with naïve pre-module understandings were able to develop slightly more sophisticated (more scientific) views than they had held previously. Fewer of the positive changes (≅22%) involved "jumps" of more than one level. Thus there was little indication of movement from naïve pre-module understandings to expert or scientific post-module views. In fact there was only one recorded increase from a level 1 or 2 (naïve) view to a level 4 (expert or scientific) view. For some of the prospective teachers there was no change in their understandings in some dimensions. In addition there were some negative changes that is, instances where prospective teachers understandings of a dimension were rated lower after the module than prior to it. Most of the negative changes, in fact all but one, were associated with a single individual. This interesting development will be discussed in more detail later in this chapter. Next I discuss the prospective teachers' pre-module understandings for each modeling dimension and how those views changed.

**6.1.3 Purpose of Models**

Most of the previous research on modeling understandings revealed that many teachers, both preservice and inservice, possess naïve or uninformed views of the nature of scientific modeling. The results of the present study appear to confirm that situation. In the beginning of the study most of the prospective teachers (5 out of 8) held understandings of the purpose of models that were rated as Level 1 or 2 (limited or pre-scientific). Figure 6.1 shows a comparison of the prospective teachers' pre/post modeling understandings for the dimension *purpose of models*. These prospective teachers

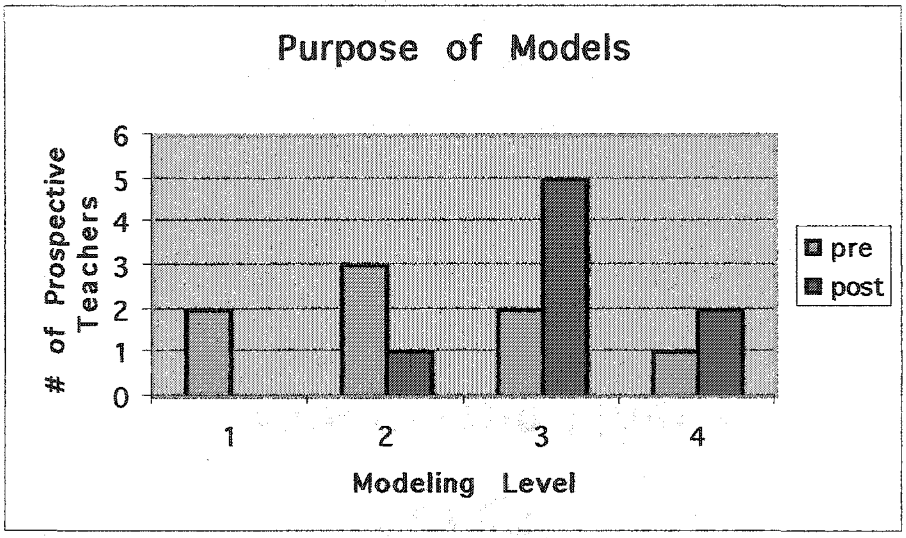



*Figure 6.1* **Changes in modeling understandings of the purpose of models.**

expressed views that compare favorably with the views of 11th-grade Honors Biology students described by Grosslight et al (1991). For example, Carl and Matt possessed Level I understandings characterized by viewing models exclusively in an educational context used as instructional aids. Van Driel and Verloop (1999a), Justi and Gilbert (2003) and Smit and Finegold (1995) all reported similar findings resulting from their research of the modeling understandings of inservice and preservice teachers. Van Driel and Verloop found that the inservice teachers they questioned focused almost exclusively on the explanatory and descriptive function of models and rarely mentioned important functions of models such as making predictions (1999a). Justi and Gilbert reported that many inservice teachers suggested that models are used for visualization; for making the invisible visible (2003). Smit and Finegold reported similar findings with prospective teachers who viewed models as tools used to help explain complex or abstract phenomenon to someone else (1995). In our own previous research we too found the instructional aid view of the purpose of models and modeling in science to be prevalent among prospective teachers. We reported previously that a prospective teacher extended this view to scientists, imagining that scientists use models to teach other scientists who are visual learners (Crawford & Cullin, 2002; Cullin & Crawford, 2002). In the present study, Carl expressed a similar notion suggesting scientists teach teachers using models:

> But then it's, it's easier for them (scientists) to like show like teachers in other subject areas what they have to do. (Carl, pre-interview, 4/1/02, line 71)

Jane, Jean, and Jackie each expressed views of the purpose of models that were rated as Level 2 that, like Level 1 views, were linked to educational settings. A Level 2 view acknowledges that a model is used by someone who is trying to understand something as opposed to being used by someone who understands to explain it to someone else. Jean imagined that models could be used by an individual to help them understand a phenomenon for themselves by giving them something on which to test out their ideas:

> They can maybe when they put it into a model they can see and they do more research, they can see maybe what would work and what wouldn't because it will be 3-D. And like they can either support or negate what they thought before if they've put it to use in a model. (Jean, pre-interview, 3/29/02, line 92)

Three of the prospective teachers, Kate, Marvin, and Clyde, had fairly sophisticated understandings of the purpose of models prior to the module. Marvin and Clyde possessed an engineering view of models in which ideas are tested out on models and then applied to the design of some product. A familiar application of this view is model airplanes whose aerodynamic designs are tested in wind tunnels. The following quote from Marvin exemplifies this view:

> … I think I said a model is something that you design ahead of time that you try to reflect how, you know, it reflects something that will actually be applied in the real world. (Marvin, pre-interview, 3/29/03, line 566)

Clyde, who had done organic chemistry research with plant abstracts, imagined using models to test out compounds to find combinations that might be the most promising ones to examine further. Kate, a prospective Earth and Space Science teacher, recognized that models are the only means at scientists' disposal for studying complex and/or dangerous phenomena. She recognized the important role of models in contemporary science citing global climate models and their influence in informing policy. Views such as those expressed by Kate, Marvin, and Clyde were not commonly reported in the literature among pre-college students, preservice, or inservice teachers. Grosslight et al. (1991) only reported that those individuals described as modeling "experts" expressed sophisticated understandings of the purpose of models. Van Driel and Verloop (1999a) reported that few of the inservice teachers they interviewed mentioned important functions of models such as "making predictions." Justi and Gilbert (2003) however reported that a high percentage of inservice teachers they interviewed recognized making predictions as an important purpose of models. It is important to note that most of the participants in Justi and Gilbert's study held multiple views of the purpose of models, some of which were less scientific than others.

The changes in the prospective teachers' understandings of the *purpose of scientific models* were similar to the general trend recorded for all of the dimensions. After the module many (5 out of 8) of the prospective teachers possessed level-3 understandings. They viewed a model as a tool used in place of the target to investigate events related to the target that would be otherwise dangerous or destructive. Many referred to what could be called "What if?" scenarios in which some aspect of s system could be varied and the effects of this variation observed with a model. The following quote from Carl captures this view:

> . . . before like even in places like say a factory were going to be around the pond. You could show what would happen if like an increase of pollution came in. So there's a lot of different things you could do by just having a model where, where it would be just as good as like if you were at the pond. (Carl, post-interview, 4/29/02, line 44)

This view is not fully scientific in that it fails to acknowledge that the process of getting the model to behave like the target is a means by which new understanding about the target can be generated. The exploration of "what if?" scenarios using models assumes the model has already been designed to behave like the target.

### 6.1.4 Building Models

Little is reported in the literature about understandings related to how models are built. The results of the present study are therefore especially informative on this dimension of modeling understanding. Much of the emphasis of researchers focused on gauging how the relationship between the model and the target was viewed. This aspect of building models was investigated in the present study. Additional emphasis was placed on examining the prospective teachers' understandings about how scientists construct models since building and testing models were the capstone experiences of the module. There are no references to this aspect of building models in the existing literature.

It has been demonstrated that 7th-grade students typically suggested that there be a one-to-one consistency between the model and the target (Grosslight et al., 1991). In other words, a model should be exactly like the target. Smit and Finegold reported that prospective teachers held similar views suggesting that the model should be identical to the target (1995). In contrast to this view, Grosslight et al reported that Honors Biology 11th-graders recognized that differences between the model and target were acceptable. Instead, most of them suggested that the purpose of the model mediates its construction. The prospective teachers in this study had a similar view.

Most of the prospective teachers started with understandings of building models rated as Level 1 or Level 2 (limited or scientific). Figure 6.2 shows a comparison of the

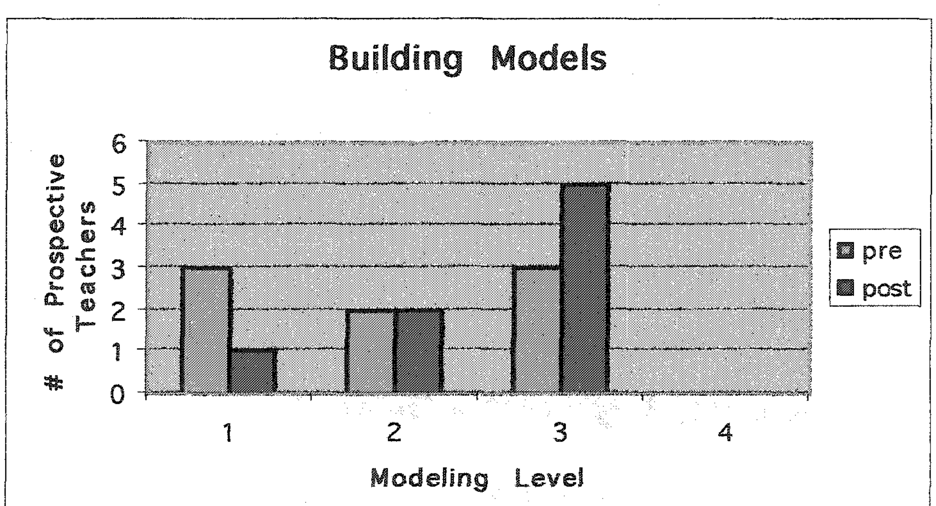



*Figure 6.2* **Changes in modeling understandings of building models.**

prospective teachers' pre/post modeling understandings for the dimension *building models*. Jackie, Jane, and Matt had level 1 pre-module understandings of building models. Their focus was on the information that was being imparted and making sure that the model being used had the correct level of detail. Each had a slightly different focus. Matt was concerned with scale, Jackie with correctness, and Jane developmental appropriateness. This view was similar to those of Honors Biology 11th-graders as reported by Grosslight et al who suggested that models needed to be "understandable to yourself and others (1991, p.810)." Such concerns are commensurate with a view of the purpose of models as instructional aids.

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Carl and Jean whose understandings were rated as Level 2 (pre-scientific) each included an aspect of building models that showed their understandings to be more scientific. Carl acknowledged the iterative nature of model building:

> Probably just by brainstorming and scientists sitting around like plugging away at like what they think should be involved and what they shouldn't, what shouldn't, and actually coming up with what they feel is a good model. (Carl, pre-interview, 4/1/02, line 297)

Jean emphasized the relationship between the modeler's ideas and the model itself:

> Given what they know what is known, they can make those like the constants. And then maybe learn other things by manipulating the knowns. (Jean, pre-interview, 3/29/02, line104)

Kate and Clyde, who had more sophisticated, Level 3 understandings prior to the module could not articulate a process for building models per se but were clearly aware that the goal in building models is to get the model to behave like the target. Kate clearly articulated this view:

> It has to be, it has to act, it doesn't have to look the same way. It has to behave the same way. As, I mean, the more similar it behaves the more, better model it could be. (Kate, pre-interview, 4/1/02, line 165)

The changes in understandings of *building models* were similar to the general trend recorded for all of the dimensions. The most common changes were from level 1 to level 2 understandings and from level 2 to level 3 understandings. The level-3 understandings that many appeared to hold after the module were characterized by acknowledging that the relationships among the variables in the target were important. Carl expressed this view:

> … you have to keep in mind the relationships between things and how changing one thing about the model, how everything else will be affected. (Carl, post-questionnaire)

None of the prospective teachers expressed a scientific or expert-like view of building models. Those who possessed Level 3 understandings prior to the module did not express views more sophisticated views after the module. A scientific view of building models should clearly emphasize the iterative nature of model building including repeated observations of the target (or available date related to the target) in order to get the model to behave like the target. Getting the model to behave like the target necessitates including appropriate relationships among variables as exist in the target phenomenon.

**6.1.5 Changing Models**

There is a considerable amount reported in the literature regarding changing models. Perhaps the most important understanding related to this dimension is whether or not one imagines that models could change. It appears that pre-college students, prospective teachers, and inservice teachers are generally of the opinion that models can be changed. Justi and Gilbert did report that some teachers they interviewed believe that models do not change. However, careful examination of this view suggests that these teachers merely believed that a correct model exists for a given phenomenon. Differences in views regarding changing models are generally attributable to what one imagines prompts changes in a model. Seventh graders often suggested that models are changed if they are found to be incorrect or wrong, but they did not provide an explanation for how the "correctness" of a model might be determined (Grosslight et al, 1991). Eleventh grade honors biology students that new information about the target might be obtained via research, experiment, or discovery. However they failed to acknowledge the models' role in the acquisition of new information about a target (Grosslight et al., 1991). Van Driel and Verloop reported similar results from their work with inservice teachers who suggested that models are changed when new data about the target are obtained (1999).

Prior to the module, I found that the prospective teachers held views similar to those of $11^{th}$-grade Honors Biology students and inservice teachers. Most of the prospective teachers (5 out of 8) started with understandings of changing models that were rated as Level 2 (pre-scientific). Figure 6.3 shows a comparison of the prospective teachers' pre/post modeling understandings for the dimension *changing models*. They

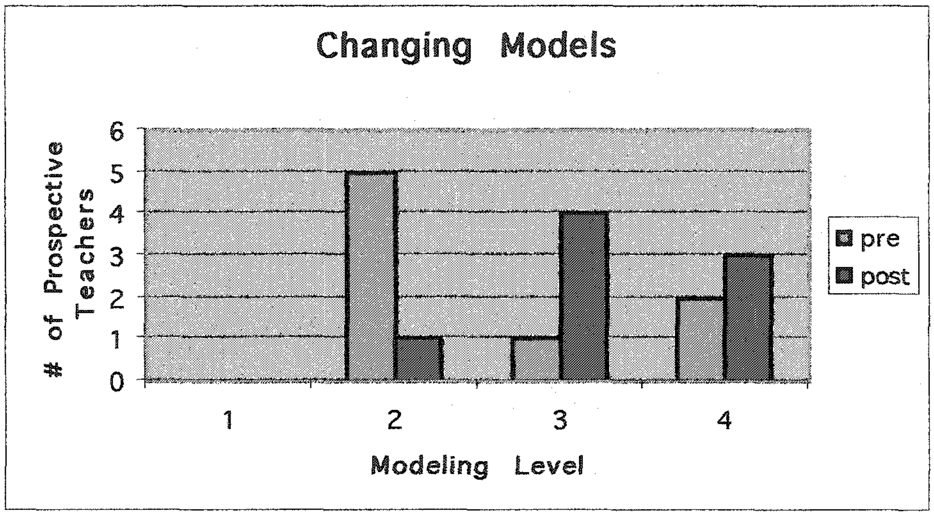



*Figure 6.3* **Changes in modeling understandings of changing models.**

were adamant about the tentativeness of models, but they often mentioned ambiguous new discoveries as the catalyst for changing a model. Jean's view was typical of many of the prospective teachers in this regard:

> Maybe something they didn't think about before or a new . . . if something else from another scientist or another person is discovered or, or thought of, then they can maybe apply it to what they know and it will change everything. It could change everything. (Jean, pre-interview, 3/29/02, line138)

Those with more sophisticated pre-module views typically recognized that models are changed when their behavior is not in agreement with the behavior of the target. For example, Clyde acknowledged that incongruent results would prompt changes in a model:

> Well if the, if it comes up as invalid then they didn't represent something in the . . . they either misunderstood or didn't consider something in the

> actual phenomena that's relevant to actual data they collected. (Clyde, pre-interview, 3/29/02, line 154)

Marvin, who consistently espoused an engineering view of models, proposed a different reason for changing a model. In his view models are changed in the design process until an optimal design is achieved:

> It helps you make a better model. Improve on your, on your existing model till you get to the best one you can possibly have.
> (Marvin, pre-interview, 3/29/03, line 101)

The changes in understandings of the dimension *changing models* were slightly different than the general trend recorded for all of the dimensions. The greatest tendencies among the participants were to show no change or change from level 2 to level 3. After the module, those with Level 3 views acknowledged that models changed when the predictions made with the model do not agree with observations of the target. Scientific or expert-like understandings would include acknowledging that the relationships built by the modeler among the variables are what would likely need to be changed. It is important to note that Matt showed movement from a naïve (Level 2) pre-module understanding to a scientific or expert-like (Level 4) post-module understanding. This is the only such instance of reaching expert status when having started with a naïve view for any prospective teacher in the study in any dimension.

### 6.1.6 Multiple Models for the Same Thing

The dimension of modeling understanding multiple models for the same thing is one that had received a moderate amount of attention in the literature. Teachers' and students' views of multiple models seem to be closely linked to their view of the purpose of models. As discussed above and in Chapter 2 of this thesis, an explanatory or instructional aid view of models is quite prevalent among the key participants in science teaching and learning. Many pre-college students viewed multiple models for the same phenomenon to be the result of different views (such as inside or outside) or angles of view of the target (Grosslight et al., 1991). Others viewed multiple models as focusing on different aspects of the target. Some inservice teachers, according to Justi and Gilbert, viewed multiple models to be the result of some being more comprehensive or detailed than others to aid in explanations for audiences of different levels (2003). Van Driel and Verloop however found that many inservice teachers view multiple models as representing researchers' interests or theoretical points of view (1991). This is a much more scientific view of multiple models than the view described above where the level of detail was the aspect that was emphasized. A scientific view would acknowledge that different models might focus on different aspects of a complex system and multiple models could represent competing explanations of the target phenomenon. The only instance reported in the literature where this view was articulated was by the experts in the Grosslight et al. study (1991).

Prior to the module the prospective teachers in the present study, viewed as a group, expressed all of the views discussed in the preceding paragraph. However, when considered individually half of the group was rated as having Level 2 views, similar to precollege students' and inservice teachers' views. Figure 6.4 shows a comparison of the prospective teachers' pre/post modeling understandings for the dimension multiple models for the same thing. Rating the views in this dimension was somewhat problematic because there are two "scientific" views associated with this dimension. First, scientists often model components of a system or phenomenon so they may only want to focus on

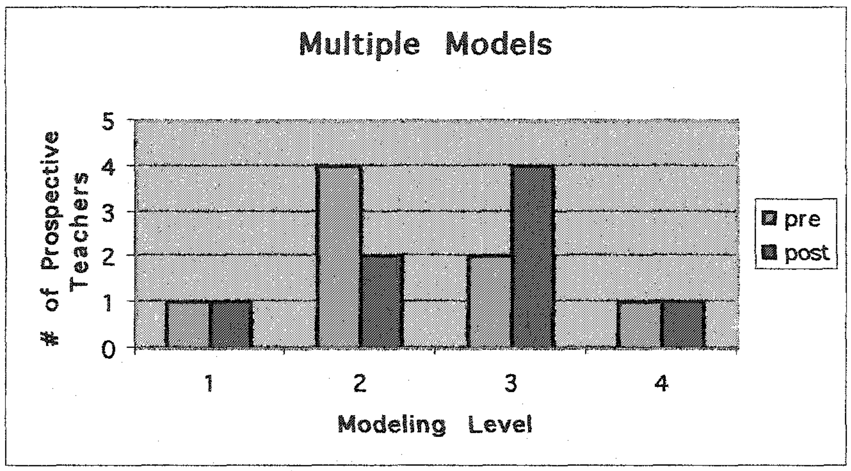



*Figure 6.4* **Changes in modeling understandings of multiple models**

those components and therefore purposely neglect other components. Second, since models represent a modeler's ideas or explanations about unexplained phenomena, multiple models can represent competing explanations. Prospective teachers' views were rated as emerging scientific if they expressed one of these views and scientific if they expressed both. Those who started with Level 2 understandings typically expressed some relationship between multiple models for the same target and different modeler's views. Jackie expressed this view:

> Different people have different ideas. So then they can have their different models and then test out their ideas. (Jackie, pre-interview, 4/1/02, line 270)

Carl, Jackie, and Jean showed no change in their understandings after the module. Jean, who had Level 3 understandings prior to the module, recognized that multiple models could represent competing theories but never acknowledged that different models could focus on different aspects of the same system or phenomenon. Carl and Jackie never made either connection but still recognized that multiple models were the result of different modeler's ideas. Matt, who moved from Level 1 to Level 3 understandings recognized the connection between multiple models and competing theories after the module:

> … I started to go was there's two different theories. So obviously there would be two different models. (Matt, post-interview, 5/1/02, line 370)

Kate's presented somewhat of a dilemma during the rating phase of analysis. She was rated as having less scientific views of this dimension *after* the module, than she had prior to it. She clearly articulated both scientific views prior to the module, but only one after the module. There is no reason to believe her view changed. However, since there was not enough evidence to support rating her as having scientific views after the module, she was rated as having emerging scientific views.

### 6.1.7 Validating Models

There is perhaps less existing literature on views of how models are tested and validated than any other dimension of modeling understanding. A few of the inservice teachers interviewed by Justi and Gilbert suggested that models are validated by the modeler, other scientists, or by the community of scientists (2003). In the few instances when the subject of testing and validating models was raised, pre-college students were more likely to suggest the testing of designs than of testing explanations. The former is consistent with an engineering view for the purpose of models.

The prospective teachers prior to the module represented the entire spectrum of views of validating models. Figure 6.5 shows a comparison of the prospective teachers' pre/post modeling understandings for the dimension validating models. Prior to the

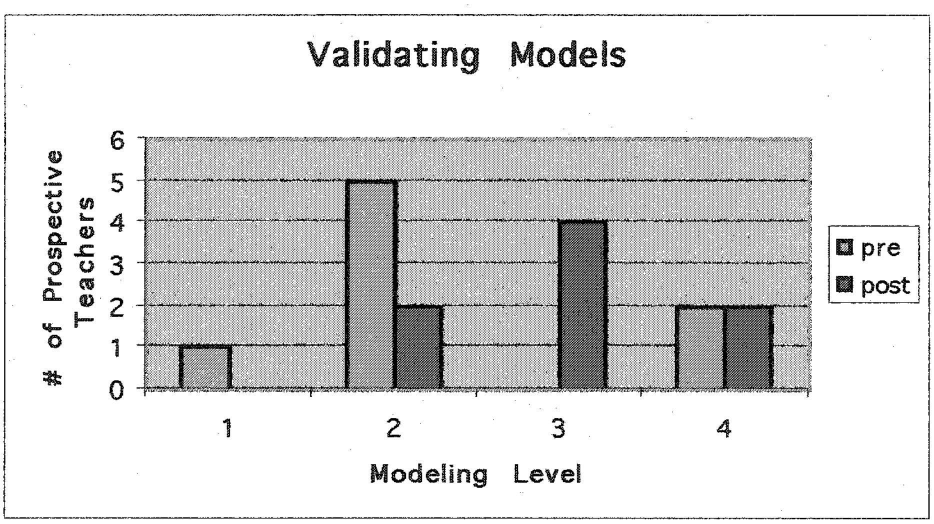



*Figure 6.5* **Changes in modeling understandings of validating models.**

module half of the prospective teachers possessed Level 2 understandings of validating models typified by acknowledging that models are indeed validated. There was little consistency in the means they described though. Carl for instance suggested that models are passed on to the scientific community via publications:

> Probably the same process of like having a paper published like you know peer review and stuff. Just a bunch of stuff like that. Sending them out and then going for a review board and them having you ask all kind of questions about why you did it like this and what reasons for everything

> and you have it explained. And then after that I'm sure it's kind of accepted. (Carl, pre-interview, 4/1/02, line 299)

Jean made vague references to hypothesis testing suggesting that models are not proven but instead disproved:

> I think what most scientists, well from what I understand, is that they don't necessarily try to prove something. They try to find things to negate something to like make it not work. (Jean, pre-interview, 3/29/02, line123)

The changes in understandings of the dimension *validating models* were similar to the general trend recorded for all of the dimensions. Three of the prospective teachers changed from level 2 to level 3 understandings. Those prospective teachers who demonstrated level 3 understandings after the module emphasized the agreement between the prediction of the model and observations of the target. The change is apparent in Carl's post-module comments:

> Just by going and like looking at your model and going to the pond and looking a the conditions the pond is at and making the settings on your model the same as what the pond was and getting the same results like time after time. (Carl, post-interview, 4/29/02, line 218)

Someone with expert-like understandings would also recognize that positive agreement between a model's predictions and observations of the target might mean that the modeler "got it right" and disagreement would indicate that the model would need to be adjusted.

**6.1.8 Comparing the Prospective Teachers' Pre/Post-Module Understandings and Those of Pre-college Students as Reported in the Literature**

The prospective teachers in this study showed important, positive changes in their modeling understandings. As I discussed in Chapter 2 of this thesis, there are very few studies in the literature that report on attempts to enhance modeling understandings. None exist in which teachers' understandings, inservice or preservice, are the objects of change. However there are two studies involving pre-college students. There are some significant similarities and differences among the three instructional interventions I have compared (Schwarz and White, 1998, Wisnudel-Spitulnik et al., 1999; and the present study). All three involved the use of computer modeling. Two of the three involved the use of Model-It (Wisnudel-Spitulnik et al. and the present study). Two of the three included real-world experiences in conjunction with computer modeling (Schwarz and White and the present study). Two of the three included explicit instruction (Schwarz and White and the present study). The study reported by Schwarz and White involved a 10.5 week intervention. The other two involved interventions that were significantly shorter in duration.

In the studies, experiences working with scientific models resulted in students developing fairly sophisticated understandings of the purpose of models. Both Schwarz and White (1998) and Wisnudel-Spitulnik et al. (1999) reported that students identified one purpose of models to be to make predictions. The students in the study reported by Schwarz and White also recognized models, especially computer models, as being useful for testing alternative models. The prospective teachers in the present study also came to potential to reveal gaps and alternative conceptions of domain-specific knowledge held by some of the prospective teachers

**The Models Alone Shed Little Light on One's Modeling Understandings**

The models, when used alone as an assessment, revealed very little about the prospective teachers' understanding of models and modeling. The computer models did not reveal the process that went into their construction. Instead, one can only view the end-result, the final product, as a static artifact. Stratford noted that by examining pre-college students' models built using Model-It, he could not know whether or not a given relationship was the result of intense testing and revision (1995). One could assume that better models are generally the result of better modeling. However, such an assertion appears to be a shaky one from analyzing only the models. Much more was revealed when the models were examined in conjunction with the process-video of the pairs building those models. I will address this point in more detail, when addressing the third research question in the next section of this chapter.

**Models Reveal Gaps and Alternative Conceptions of Scientific Knowledge Related to Pond Ecosystems**

The models did however provide insight into the domain-specific knowledge of the prospective teachers. It is impossible to disaggregate the knowledge of pond ecosystems of individuals in each pair, but there were some striking omissions and misconceptions in some of the models. One might expect, given that a pair worked together on each model, fewer instances of alternative and limited scientific information. One the one hand, some of the prospective teachers exhibited quite adequate knowledge view models as being useful in making predictions of the behavior of the system also. However, only those prospective teachers who held more scientific views prior to the module mentioned the usefulness of models in idea-testing.

Schwarz and White also reported that pre-college students showed mixed gains with regard to validating models (they termed it model evaluation). Many students expressed the view that any model was as good as any other. The prospective teachers in the present study appeared to have developed a more scientific view about validating models. Most recognized that agreement between the behavior of the model and target is important in determining the validity of a model.

**6.2 Discussion of the Models Built by the Prospective Science Teachers'**

In this section I will address the second research question, *"What is the nature of the models prospective science teachers construct during the modeling tasks?"* I will begin by making two assertions. Next I will compare the models built by each pair of prospective teachers during the first modeling session followed by a similar comparison of. the models they built during the second modeling session.

**6.2.1 Assertions for Research Question #2**

In this section I make two assertions related to the nature of the models built by prospective science teachers: 1) models built by the prospective teachers reveal little about their understanding of the nature of models and how scientists use modeling per se, when the models are considered as independent artifacts; and 2) the models have in this domain. On the other hand, some of the prospective teachers possessed alternative, and in some cases quite limited, knowledge of pond ecosystems. The limited understandings are cause for great concern.

### 6.2.2 Nature of Session 1 Models

Following the field study of a pond in a wooded setting, prospective teachers working in pairs built an initial computer model of the pond to address the driving question. Following a second field study that involved studying a different pond near the first pond, but one in a non-wooded setting, the prospective teachers revised their original model. They were asked to use the model to answer a question of their own choosing. An extensive description of the modeling module can be found in Chapter 3 of this thesis. I assessed the Session One models using a rubric that permitted me to compare both quantitative as well as qualitative aspects of the models. The quantitative score represents the complexity of the model and the qualitative score the scientific accuracy of the model. The quantitative aspects included the number of objects, variables, relationships, and inter-relationships. The qualitative aspects included components of the model I identified as essential or critical, as well as the accuracy of the relationships that were built. Table 6.2 compares the qualitative and quantitative modeling scores for each of the four pairs with the score of a "standard" model that could be considered to contain all of the essential objects, variables, and relationships inherent in a pond.

Table 6.2

**Comparison of prospective teachers' models quantitative and qualitative scores**

| Pair | Quantitative Score | Qualitative Score |
|---|---|---|
| Kate/Matt | 108 | 33 |
| Jane/Carl | 84 | 29 |
| Jean/Clyde | 68 | 27 |
| Jackie/Marvin | 52 | 15 |
| *STANDARD* | *45* | *37* |

For the purposes of this discussion refer to Figure 6.6 and Figure 6.7, as examples of the strongest model and the weakest model. It is clear that Kate and Matt built a model that was both quantitatively and qualitatively superior to the models built by the other pairs. Their model (see Figure 6.6) was more complex and scientifically accurate. It contained all of the critical objects and variables identified in the Standard Model. What contributed to the complexity of Kate and Matt's model was the number and quality of the relationships they built into their model. Their model contained almost twice as many relationships as the models built by any of the other pairs. Kate and Matt included all but two critical relationships in their model. The only critical relationships they neglected to include were those associated with the pond food chain. Another factor that added to the complexity of Kate and Matt's model was that it contained more than two times the number of variables that were interconnected (i.e. involving in a relationship with more than one other variable) than any other pair.

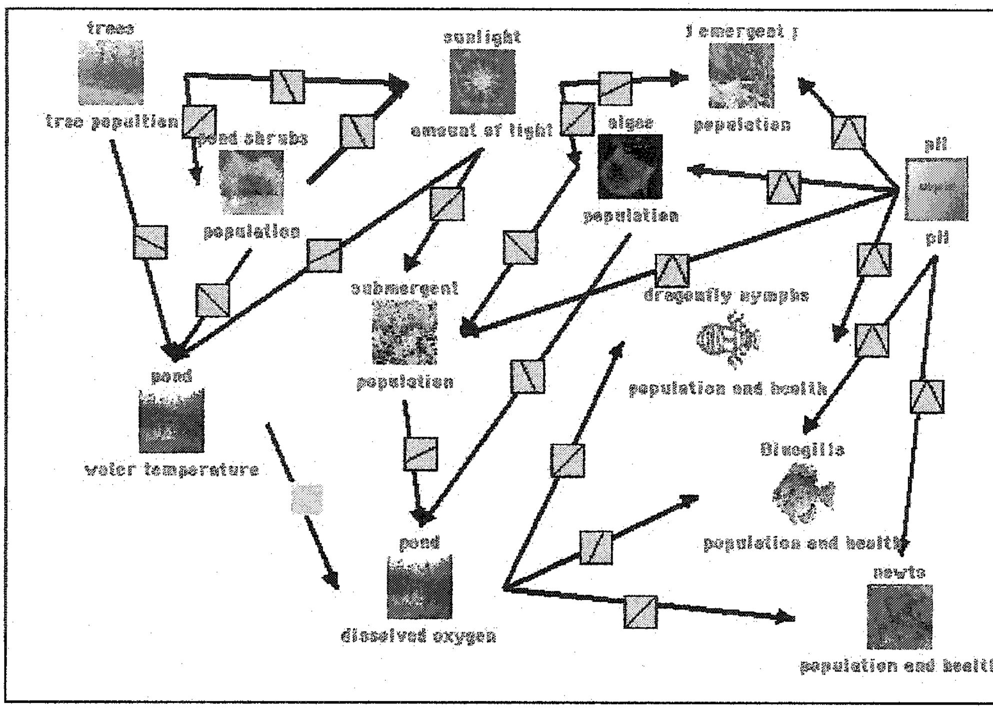



*Figure 6.6* **Kate and Matt's Session 1 Model**

The models of the other three pairs included most of the critical objects and variables. There were a few missing objects. The pair, Jane and Carl, and the pair, Jean and Clyde, neglected to include the population of macroinvertebrates in their models. Jackie and Marvin neglected macroinvertebrates as well and also inexplicably neglected to include fish in their model (See Figure 6.7). Jean and Clyde included the pond food chain in their model, but neglected building relationships between pH and aquatic plants and macroinvertebrates, as well as building a relationship between aquatic plants and dissolved oxygen. Jane and Carl neglected to include the pond food chain in their model as well as relationships between pH and aquatic plants and macroinvertebrates. They did, however, include the relationship between aquatic plants and dissolved oxygen. The quality of the models varied across the pairs. Jackie and Marvin made a weak model that

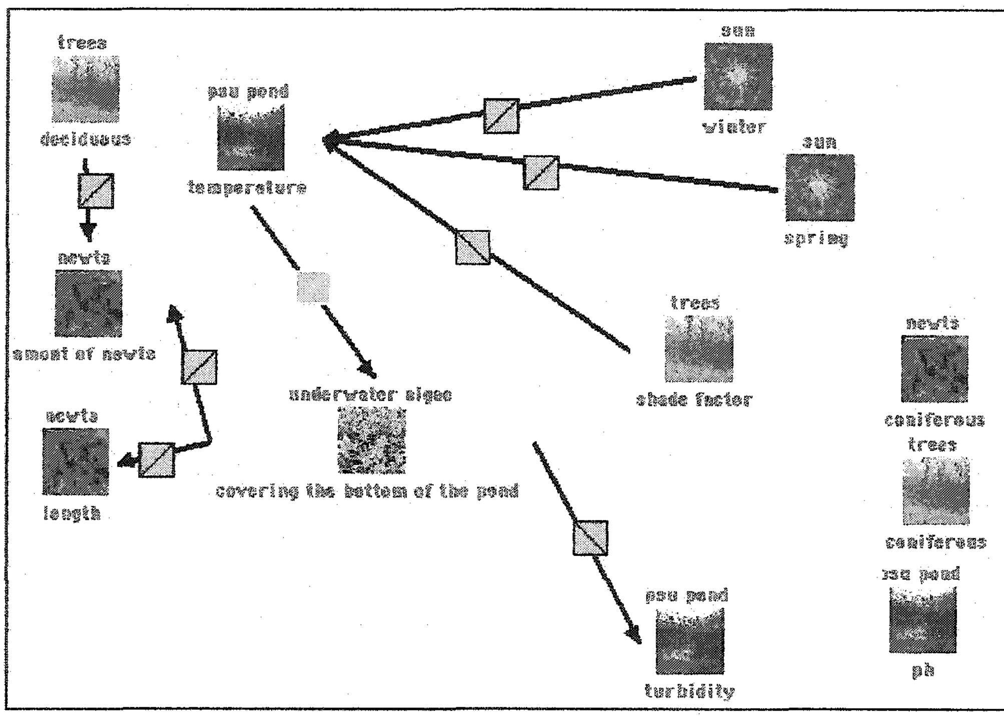



*Figure 6.7* **Jackie and Marvin's Session 1 Model**

only included one critical relationship. Jane and Carl and Jean and Clyde had three interconnections and Jackie and Marvin had one.

An important point related to domain-specific knowledge was revealed in Jean and Clyde's model. In their model they included relationships that suggested that they had an alternative conception about what effect trees have on the air quality in a forest and what effect that air quality has on the chemical composition of the pond water. They included relationships suggesting that the number of trees affects the amount of oxygen and carbon dioxide in the air. They also included relationships between the amount of oxygen and carbon dioxide in the air and the amounts of those gases dissolved in the pond. These are major non-scientific understandings ones you would not expect to see among sophomore/junior level college students preparing to become secondary biology and chemistry teachers. Jean and Clyde also neglected to include a relationship between aquatic plants and the dissolved oxygen in the pond.

Jackie and Marvin, an elementary education major and a secondary physics education major, respectively, appeared to know very little about pond ecosystems. This lack of accessible knowledge was apparent, despite our efforts during the module to provide some basic instruction and field experiences in that regard. Jackie and Marvin did not include fish in their model, and although they did create a pH variable for the pond, they did not include it in the model. They also neglected to include dissolved oxygen as a variable.

### 6.2.3 Session Two Models

Comparing the session two models was difficult due to the nature of the modeling assignment given for that session. Each pair was asked to revise their model based on our field study of the second pond. Then they were asked to use their revised model to address a driving question of their own choosing. As a result of each pair having a different driving question, the models were necessarily different from one another. It was therefore difficult to compare the models. The pairs that had previously neglected to include the variable pH, added this variable to their revised model. This addition may have been prompted by additional information obtained via an interview with the ponds' owners. It was learned that the difference in the pH of the two ponds resulted from differences in the sources of water. The pond owners explained that the wooded pond was spring fed and the non-wooded pond's water source was from run-off. The video-taped interview of the pond owners was shown to the class prior to the second modeling session.

The final models built by pair, Kate and Matt, and pair, Jane and Carl, were comparatively much more complex and interconnected than those built by pair, Jean and Clyde, and by Jackie, working alone for the second modeling session.

In some instances the models that were built consisted of models within a model. Kate and Matt had a predator/prey model that was connected to a model that emphasized the physical and plant-life aspects of the pond. Jane and Carl actually produced a model consisting of two unconnected models. The model built by Jean and Clyde was quite similar to their original model. Jackie, who worked alone due to Marvin's absence, appeared to have started from scratch and built a new model.

**6.3 Discussion of the Prospective Science Teachers' Model Building and Testing**

In this section I will address the third research question, *"In what ways do prospective science teachers go about constructing models during the modeling tasks?"* It appears that, until now, there have been few or even no investigations of prospective teachers' approaches to building and testing models. My own previous efforts, working primarily with one other researcher, included building and testing computer models with Model-It. Our emphasis, however, was on the prospective teachers' modeling understandings with some attention focused on the prospective teachers' use of the software scaffolds inherent in the design of the software (Crawford, Zembal-Saul, & Cullin, 2002). I will therefore draw upon empirical studies involving pre-college students modeling strategies in discussing my results and conclusions since such studies (Stratford, 1996; Zhang, Wu, Fretz, Krajcik, and Soloway, 2001; Zhang, Wu, Fretz, Krajcik, Marx, and Davis, 2002) exist in the literature. I will begin by making three assertions. Next I will discuss how the prospective teachers went about constructing their models highlighting three aspects: 1) the influence of the driving question on their modeling; 2) their approaches to creating objects and defining variables; and 3) the manner in which they built and tested relationships. Finally, I will discuss what was revealed in the process-video recordings of their model building.

### 6.3.1 Assertions for Research Question #3

In this section I make three assertions regarding the ways the prospective science teachers went about the task of constructing models. 1) Some approaches to modeling influence the quality of models, while others do not; 2) Various factors inhibit prospective teachers during their modeling; and 3) Prospective teachers can become frustrated with certain aspects of scientific modeling.

**Productive and non-productive modeling strategies**

Analysis of the prospective teachers' modeling strategies coupled with analysis of the models they built suggested that certain strategies have a profound effect on the quality of the models, while others appear to have little or no effect. First, the extent to which the driving question guided the model building had a positive effect on the quality of the model. Those who were clearly focused on the driving question built superior models to those who were not focused on the driving question. Different approaches taken during initial stages of model building, that is creating objects and defining variables, did not appear to influence the final quality of the models. Finally it appeared that frequent, meaningful, and iterative testing during the process of building relationships led to better models, while superficial testing, *after* most relationships had already been built, did not.

**Inhibiting Factors**

Numerous factors inhibited the prospective teachers during their modeling including knowledge of the modeling software, limitations of the software, domain specific knowledge of the phenomena being modeled, and modeling knowledge. It is possible that these inhibiting factors existed in conjunction with some of the ineffective modeling strategies discussed above thereby compounding the disruption they caused. Some of the prospective teachers clearly did not have a clear understanding of the operation of the Model-It software such as neglecting to vary an independent variable while testing. One pair wasted a considerable amount of time running useless tests. Wasting time can be disastrous when time is extremely limited as it was during the instructional module in this study. Perhaps more time should have been spent in instruction in the use of the software and a review of the software operation could have been provided at the beginning of the second modeling session.

Trade-offs between functionality and ease-of-use are often present in computer software. Model-It permits novice modelers to build fairly sophisticated models quickly and easily. However, making Model-It easy to use has limited some of its capabilities.

Specifically, the inability to run cyclic relationships caused two pairs of prospective teachers to waste time. One of the groups did not become bogged down by this limitation but the other group never really recovered.

The prospective teachers domain-specific knowledge and modeling understandings no doubt influenced the quality of the models and modeling. The interplay of these factors will be discussed in more detail in section 6.4 of this chapter.

**Aspects of modeling are frustrating to prospective teachers**

Some of the prospective teachers were frustrated with certain aspects of scientific modeling. Two aspects of the process of modeling appeared to be particularly frustrating to them. First, building a model, comprised of inter-relationships of which one might be unsure, involves taking risks. Not knowing can be disconcerting. It has been suggested that learners' tendencies to persist when confronted with difficult tasks is affected by their learner orientations (Bransford et al., 2000). Dweck suggested two kinds of learning orientations (1989). Those who are *learning oriented* like new challenges and those who are *performance oriented* are worried more about making errors than about learning (Bransford et al., 2000). It is possible that the some of the pairs held performance orientations resulting in their decisions to exclude relationships of which they were unsure. They may have reasoned that they couldn't be wrong about a given relationship if they didn't include it in their model. Unfortunately, as it pertains to the development of new knowledge, science is less about getting the one right answer and more about developing explanations or arguments, in light of available evidence. Kate and Matt, in contrast to the other three pairs, never encountered the obstacle of "not knowing" and thus did not consciously exclude any relationships of which they were unsure. There are two possible explanations for this fact. They may have been sure of all of the relationships they built or they were not uncomfortable including relationships of which they were unsure in their model. The other three groups consciously chose to eliminate or neglect relationships of which they were unsure. It is likely that many of the prospective teachers have never been asked to develop an explanation or argument for a phenomenon about which someone nearby (a teacher) did not know the "real" explanation.

A second source of frustration was that some of the prospective teachers did not see virtue in modeling because the modeler decides on what goes into the model. They perceived this to mean that a model cannot produce new or valuable information. This view speaks to the prospective teachers' modeling understandings. The model becomes the repository for the modeler's ideas (Hulse, 2002personal communication). Testing the behavior of the model against the behavior of the target either lends credence to the modeler's ideas or refutes them. This is the power of modeling and the essence of model-based reasoning.

**6.3.2 Driving Questions**

Some of the prospective teachers were more goal-driven than others. In other words, addressing the driving question appeared to truly guide the model building and testing. Zhang et al (2002) in a study comparing the modeling practices of middle school students and experts found that middle school students exhibited some expert-like practices but the quality of those practices differed from those of the experts. Specifically, the authors suggested that experts had clearer goals and provided explanations that were more supported with evidence. In the present study, two of the four pairs (Jane and Carl, Jackie and Marvin) did not appear to be goal driven during the first modeling session. Jackie and Marvin never created a fish object and Jane and Carl did not build a relationship between the number of trees and the amount of sunlight falling on the pond until there were less than 2-minutes remaining in the modeling session. Goal focus was again an issue during the second session. Three of the four pairs (Jane and Carl, Jean and Clyde, Jackie) labored at times, as revealed in their conversations, to identify a driving question. For instance, there were four episodes, some occurring more than halfway through the second modeling session, in which Jean and Clyde discussed what their driving question should be. The following excerpt shows one of these discussions:

> C: … I can't think of a way to incorporate
> J: me neither… why don't we just do… let's think of our question… what was yours? Were you thinking of one with the pH?
> C: I'm not sure…anything I was thinking about was lost… um,
> J: it doesn't matter, there's no right or wrong… whatever we want… we could say that temperature changes drastically or the… there's a… the number of trees totally… there was a hurricane and all if the trees were totally lost… it doesn't matter… pH…
> C: the only variable we're given to start with is the number of trees…
> J: So (inaudible)
> C: So, that changes everything else… I thinking of how we're going to work with this… Oh wait, wait… this is dependent, everything's dependent
> J: it doesn't matter
> C: No, I'm just trying to get an idea (Jean and Clyde, second use of Model-It 4/18/02, episode 18)

Jean and Clyde eventually settled on a question similar to the original driving question in which temperature was varied and its effects on the pond ecosystem examined.

**6.3.3 Creating Objects and Defining Variables**

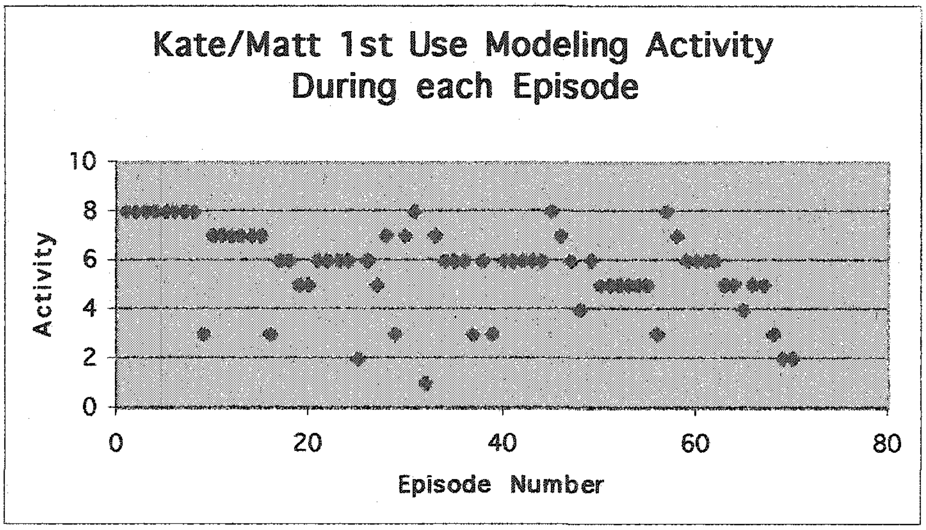
Through my analysis I found that the prospective teachers engaged in two general patterns of activity in the early or planning stages of the first modeling session: the *stepwise* and *alternating* patterns. Model-It structures model building into three general activities or modes: planning (creating objects and defining variables), building (building relationships among variables), and testing (varying one variable and measuring the effects on other variables). Each pair demonstrated one of the two patterns while in "Plan" mode. Three of the four pairs (Jackie and Marvin, Jean and Clyde, and Matt and Kate) followed the *stepwise* pattern of first creating objects in the model (the pond, fish, algae, etc.) and then defining variables for those objects. The *alternating* pattern, used by Jane and Carl only, consisted of creating an object and then defining variables for that object before creating a new object and variables for the new object.

The patterns I described above have not been reported in the literature and this may be because it appeared to be of little consequence. The prospective teachers, regardless of the pattern that typified their efforts in "Plan" mode, created most of the objects and variables in their models before moving to "Build" mode. There did not appear to be any correlation between the pattern demonstrated in "Plan" mode and the quality of the models that were built. Kate and Matt, as discussed in section 6.2 of this thesis, built a model that was superior to those built by the other three pairs. Their efforts while in the planning stages were typical of the stepwise pattern. In contrast, Jackie and Marvin, produced a weak model while following the same stepwise pattern. It is worthy of note that the Model-It tutorial, which I used as a guide in teaching the prospective teachers to use the software, followed a stepwise pattern. Jane and Carl and Jean and Clyde built models similar in both quantitative and qualitative aspects, each using a different while in "Plan" mode.

**6.3.4 Building and Testing, Relationships**

It was not until the prospective teachers began building relationships that a meaningful difference in their approaches to model building appeared. Stratford, in his comprehensive study of pre-college students models and modeling strategies found a high correlation between sound modeling strategies and sound models (1996). Testing a model and comparing its behavior to expectations and optimally the behavior of the target system itself, is an absolutely critical component of scientific modeling. A third pattern, an *iterative* pattern of testing, was evident in one of the four pairs during the first modeling session that was not evident among the other three pairs. Before discussing this pattern it may be useful to view Table 6.2 again which displays the qualitative and quantitative scores of the prospective teachers' models during the first modeling session. Kate and Matt built an excellent model. Jane and Carl and Jean and Clyde built reasonable models; the latter containing a couple of alarming misconceptions. Jackie and Marvin built a relatively weak model. During the first modeling session Kate and Matt worked cyclically, alternatively building relationships, testing their model, revising their model often adding additional objects and variables before building other relationships.

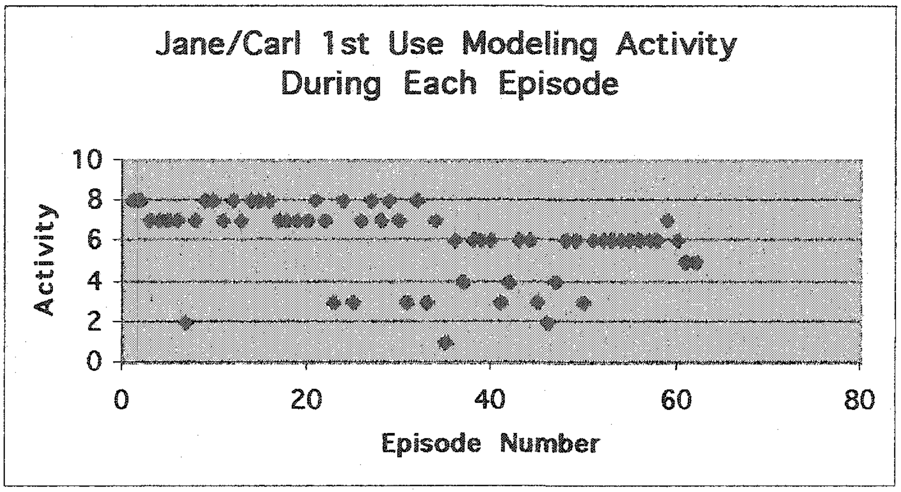
They typically built a few relationships before testing the model. The other three pairs built almost all of their relationships before doing any test-runs of their models. The episode graphs of the modeling activities depict the difference in relationship building approaches. Figures 6.8 (Kate and Matt) and 6.9 (Jane and Carl) show process maps of




**Activity Designations**

8 - create object
7 - defined variable
6 - built relationship
5 - tested model
4 - revised model
3 - discussion
2 - questioned instructor
1 - other

*Figure 6.8* **Process Map of Kate and Matt's First Use of Model-It Showing Iterative Pattern**




**Activity Designations**

8 - create object
7 - defined variable
6 - built relationship
5 - tested model
4 - revised model
3 - discussion
2 - questioned instructor
1 - other

*Figure 6.9* **Process Map of Jane and Carl's First Use of Model-It Showing Little Iteration** modeling activities for during the first modeling session. The iterative pattern is clearly evident in the case of Kate and Matt whereas Jane and Carl merely built numerous relationships before engaging in any testing.

Not only did the pattern of testing differ among the pairs but the frequency and quality of the testing differed as well. Figures 6.8 and 6.9 also show that Kate and Matt did considerably more testing than did Jane and Carl. Kate and Matt tested their model throughout the session while Jane and Carl did so only at the very end of the session. Jean and Clyde did more testing than Jane and Carl but less than Kate and Matt. Jane and Carl also did all of their testing near the end of the session after they had built most of their relationships. They did however make some revisions to their model based on the results of the test-runs. Jane and Carl only set up two test-runs, never running one of them, and did not have time to make any revisions. Jackie and Marvin did a fair amount of testing near the end of the first session. There testing was not productive though because they only tested variables that were directly connected to one another. This type of testing would not likely lead to revisions because nothing would be learned from such tests. In contrast to the first modeling session, the second session involved more time spent testing and revising the models. Revisions typically included deleting relationships and changing the rates of those relationships. The iterative pattern is more prevalent in the process maps of each of the pairs as a result. More testing is likely to take place after most of the objects and variables have been identified.

### 6.3.5 Revealing Conversations

The conversations that were recorded as the prospective teachers built and tested their models provided some insight into aspects of their modeling understandings. First, questionable decisions were made. Three of the pairs (Jackie and Marvin, Jane and Carl, Jean and Clyde) made conscious decisions to neglect relationships in their models because they were unsure of those relationships. Here Jane and Carl demonstrate such a decision:

> J: Do we want to get into that since we don't know what it is?
> C: Umm… probably not. (Jane and Carl, first use of Model-It, 4/11/02, episode 8)

There were no episodes in which Kate and Matt made a similar decision to neglect a relationship of which they were unsure. They may have been sure of all of the relationships they built or not bothered by including such relationships in their model.

Secondly, conversations during the modeling sessions revealed concerns that some of the prospective teachers had with modeling. Specifically, they thought that they were answering their own questions before they viewed the results of test-runs because *they* had told the model *how to behave*. Matt, Kate, Marvin, and Clyde all made comments speaking to this issue. Perhaps Matt's comments capture their collective concerns best:

> M: The inherent problem with this is we have answered… we always answer our question before we come up with it… we're designing the relationship the way we want it to work so I guess we go out and we test it (Kate and Matt, second use of Model-It, 4/18/02, episode 44)

The power of modeling, especially computer modeling, is in the ability to capture one's ideas about how a system behaves and how its components are related and then test your ideas by comparing the behavior of the model to the behavior of the actual system to see if you may have gotten it right. Notice at the end of the passage, Matt recognized the need to test the model's predictions but did not appear to recognize this as an acceptable process.

Finally, it appeared that at times the prospective teachers were quite frustrated by building and testing their models. There were various causes of their frustration. A few of the sources of frustration can be traced to the software. Some of the prospective teachers became frustrated when the software would not do what they wanted it to do. In some instances this was due to their own misunderstandings about the way the software functioned. In other cases, limitations of the software, such as its inability to process cyclic relationships or the way the rates of relationships were defined, were sources of frustration. In addition to difficulties with the software, some of the prospective teachers were frustrated by not having an understanding of the science involved—not knowing about certain relationships. Marvin expressed his frustration about not having data or information upon which to base relationships:

> M: Right, that's what I was just saying. We have nothing for pH. We could make something up. See, this is where you need data. Why are we coming up with these cause and effect relationships? What are we basing it on? (Jackie/Marvin, first use of Model-It 4/11/02, episode 27)

Building a relationship based on how you think the variables are related involves taking a risk and is part of what makes modeling powerful. Jean and Clyde omitted relationships of which they were unsure. However Clyde did appear to recognize that including relationships of which you are unsure is part of the process of learning from models:

> C: My only problem is that if you build it into the model it's going to be based on like the
> J: increase, decrease
> C: It's going to be things that I input so I can either make it affect it or not make it affect it
> Instr: right, but that's the nature of…
> C: that's the point of the model, OK (Jean and Clyde, first use of Model-It 4/11/02, episode 21)

Not everyone was able to see this aspect of what they were doing this clearly.

**6.4 The interplay among the three research questions**

In this section I discuss the interplay among the three research questions. The prospective teachers in this study built and tested dynamic computer models of pond ecosystems and engaged in other activities designed to enhance their understandings of the role of models and modeling in science. An interesting question, in addition to those that have guided my research, emerged during my analysis, "What knowledge influenced the prospective teachers models and modeling more; knowledge of the phenomenon being modeled or knowledge of modeling?" Unfortunately, my results are inconclusive. However, the question provides an interesting problem space in which to explore. Before doing so I must address two limitations of my study that affect this discussion. First, I had the prospective teachers working in pairs. Their modeling understandings were analyzed individually but whose knowledge, either modeling or domain-specific, was being utilized during the modeling sessions could not be easily discerned. Second, I did not assess individuals' domain-specific knowledge of pond ecosystems and therefore I must rely upon assumptions in this regard.

Let us begin by considering assumptions regarding the domain-specific knowledge of the prospective teachers. There were four prospective biology teachers, one prospective chemistry teacher, one prospective earth and space science teacher, one prospective physics teacher, and one prospective elementary teacher who had chosen mathematics and science as an area of concentration. All had at least junior status suggesting that they had completed a considerable amount of their science content coursework and done reasonably well in their studies. They would not have been accepted into the teacher certification program if they had achieved poor grades. One would expect the prospective biology teachers to have a firm understanding of the life processes in a pond such as photosynthesis, respiration of plants and animals, and the pond food chain. Not wanting to rely too much on such assumptions, I attempted to familiarize all of the prospective teachers with pond ecosystems (with the help of an exceptional environmental educator). Chapter 3 of this thesis provides a detailed description of the context of the instructional module.

In Chapter 5 of this thesis and earlier in this chapter I have discussed the eight prospective teachers' understandings of the role of models and modeling. Table 6.3 displays a qualitative description of each prospective teacher's pre-module modeling understanding and the models they built as well as the science discipline in which they had been seeking teacher certification. To simplify the discussion we can consider sophisticated understandings to be Level 3 or 4 understandings and naïve understandings to be Level 1 or 2 understandings. Let us now turn our attention to what the results of my analysis revealed about the prospective teachers models and modeling.

**Table 6.3**
*Prospective Teachers' Modeling Understandings, Subject Specialization, and Models*

| Prospective Teacher | Subject Area | Pre-module Modeling Understandings | Session 1 Model |
|---|---|---|---|
| Kate | Earth/Space | Sophisticated | excellent |
| Matt | Biology | Naïve | excellent |
| Jean | Biology | Naive | adequate |
| Clyde | Chemistry | Sophisticated | adequate |
| Jane | Biology | Naive | adequate |
| Carl | Biology | Naive | adequate |
| Jackie | Elementary | Naive | weak |
| Marvin | Physics | Naïve/ Sophisticated | weak |

Kate had sophisticated modeling understandings while Matt's were naïve. Having worked with these two individuals in other courses, I have known them both to have more than adequate substantive knowledge of their subjects. Jackie had naïve pre-module modeling understandings. As I noted in Chapter 5, Marvin's pre-module modeling understandings were somewhat sophisticated and also very different than those of the other participants. Jackie, an elementary education major, appeared to struggle when working alone in Marvin's absence during the second modeling session. Having worked with Jackie throughout the semester, she often expressed concern over her "lack" of science background compared to the others enrolled in the course since she was the only non-secondary science person. I worked with Marvin on numerous occasions and had the opportunity to observe him while microteaching. As a physics teacher myself I feel confident in evaluating his subject matter knowledge and I have always considered it to be somewhat lacking. Jean, Clyde, Jane, and Carl all seemed to be competent in their subject areas based on my interactions with them throughout the semester. Clyde, a prospective chemistry teacher, had very sophisticated modeling understandings. It is also interesting to note that he had organic chemistry research experience. Jean, Jane, and Carl, all prospective biology majors, had naïve pre-module modeling understandings.

Kate and Matt made the best model. Their model did not contain flawed relationships. They were decisive and appeared motivated during both modeling sessions. Jackie and Marvin clearly made the weakest model. The other two pairs, made models that were better than Jackie and Marvin's model but not as good as Kate and Matt's model. Kate had sophisticated modeling understandings and made a sophisticated model. Clyde had sophisticated modeling understandings but made only an adequate model that contained some obvious alternative conceptions. Matt, who worked with Kate, had limited pre-module modeling understandings but made a sophisticated model. Jean, who worked with Clyde, had naïve pre-module modeling understandings and made an adequate model. There are no obvious patterns to suggest a correlation between modeling knowledge and model quality. Kate and Matt did employ better modeling strategies especially in regard to model testing. Perhaps it was Kate's sophisticated modeling understandings that prompted them to do this. If that is true, why didn't Clyde and Jean do more meaningful testing?

Turning our attention to domain-specific knowledge, there is evidence to suggest that Kate and Matt collectively had a better understanding of pond ecosystems than the other pairs. Their model did not contain erroneous relationships. Jackie and Marvin, who made a weak model, probably had the weakest knowledge of pond ecosystems. Jean and Clyde, prospective biology and chemistry teachers respectively, exhibited a lack of knowledge of pond ecosystems and of the contributions of a relatively small amount of trees to the composition of the atmosphere. As discussed in section 6.3, three of the four groups chose to neglect certain relationships in their models. Some of those relationships can be considered vital to the life in the pond; dissolved oxygen and pond temperature for instance. The decision to neglect vital relationships suggests that the prospective teachers did not know how vital they were which in turn suggests their lack of domain-specific knowledge. It would appear therefore, that domain-specific knowledge might have been more influential in the quality of the models than was knowledge of modeling. Stratford (1996) came to a similar conclusion. Based on the analysis of over 50 pre-college students models, he suggested that some of the students' abilities to demonstrate good modeling was the result of their knowledge of the stream ecosystems they had been studying for many weeks. However, the argument is based on circular logic because I am using the models as an indicator of domain-specific knowledge. In other words, the models informed me about their domain specific knowledge but I am trying to determine the affect of domain-specific knowledge on the quality of the models. Prudence requires me to conclude that my results are inconclusive.

One additional factor that contributes to the cloudiness of this issue concerns Model-It. The software is specifically designed to permit novice modelers to build and test models. The modeler is guided and supported in creating objects, defining variables, and building and testing relationships in many ways. Model-It does not provide guidance on the content of the model but certainly guides the process used to construct it. The supports in the software may hide deficiencies in modeling understanding but it cannot hide deficiencies in the knowledge of what is being modeled. The prospective teachers no doubt achieved models that would have unachievable based on their modeling knowledge alone.

**6.5 Summary**

In this chapter, I have presented numerous assertions based on the results of my analysis. While those assertions may be interesting to the reader, every researcher is obliged to answer the question, "So what?" In the next chapter I will present Implications for Science Education in three areas: 1) Implications for Science Education Research; 2) Implications for Teacher Education; and 3) Implications for Science Teaching and Learning to answer that important question.

# Chapter 7

# CONCLUSIONS and IMPLICATIONS FOR SCIENCE EDUCATION

There are two main theses of this dissertation. First, prospective science teachers subject matter knowledge, specifically their knowledge of the way that models and modeling are used in the development of scientific knowledge, is limited. Second, experiences building and testing complex models in conjunction with field experiences and explicit instruction can support prospective teachers in developing more scientific modeling understandings. This work builds upon other research, expanding the base of teacher subject-matter knowledge research in general and modeling understandings research specifically by providing a closer look at prospective teachers' articulated modeling understandings and their non-articulated understandings as revealed in their modeling strategies and models. In this chapter I discuss implications for science education. I begin with a summary of my assertions. Then I discuss the implications of what I have learned in three areas: 1) science education research, 2) science teacher education, and 3) science teaching and learning.

## 7.1 Summary of Assertions

In Chapter 6, I presented assertions related to each of the three questions that guided my research and the interplay of those questions. The first research question centered on the prospective teachers' modeling understandings. It also focused on how those understandings changed during modeling tasks that included building and testing computer models of pond ecosystems. I found, as has been reported in the literature relating to both inservice and preservice teachers, that most of the prospective science teachers' initially held naïve pre-module understandings about the role of models and modeling in science. I identified five dimensions of modeling understanding gleaned from the literature as a framework for examining the prospective teachers understandings. I found that the dimensions are tightly coupled and therefore it is unlikely for a prospective teacher to have naïve understandings in one dimension and scientific views in another. The module was designed specifically to support prospective teachers developing more sophisticated understandings of the role of models and modeling in science. I found that it is possible in a short amount of time to enhance prospective teachers' modeling understandings but in small graduations. Their understandings became more scientific but not sophisticated. Finally, I found the prospective teachers' ideas about models and modeling to be bounded by the context. They were able to articulate views of models and modeling punctuated by using models to investigate "what if?" scenarios in situations where the phenomenon in question cannot be manipulated directly for some reason. The prospective teachers were not able to transfer their views to phenomena that occurred in the distant past or that occur on an unobservable scale, phenomena where modeling is vital.

The second research question focused on models built by the prospective teachers' during two modeling sessions. I found that the models they built revealed little about their understandings of models and modeling when the models were considered as independent artifacts. More was revealed when the models were considered in conjunction with the modeling strategies that produced them. The models did however reveal that some of the prospective teachers have alternate conceptions of and gaps in their domain-specific knowledge of pond ecosystems.

The third research question focused on the strategies the prospective teachers employed while building their models during the two modeling sessions. I found that some approaches to modeling influenced the quality of models while others did not. Specifically, the order in which objects are created and variables are defined does not appear to affect the quality of the models that are built. To the contrary, cycles of testing and revising a model while building relationships among variables results in models of higher quality. I also found that various factors inhibited the prospective teachers during their modeling including knowledge of the modeling software, limitations of the software, domain specific knowledge of the phenomena being modeled, and modeling knowledge. Finally, prospective teachers can become frustrated with certain aspects of scientific modeling such as including relationships in their models of which they are uncertain.

One unique aspect of my study was that I examined the prospective teachers understandings as they were revealed in interviews, models and modeling strategies. Doing so permitted me to consider the interplay of what I learned from multiple data sources. Unfortunately, my consideration of the interplay among my research questions raised more questions than answers. The results were inconclusive. It is unclear what contributed more to the quality of the models and modeling, domain-specific knowledge or views of scientific models and modeling.

## 7.2 Implications for Science Education Research

This section discusses implications for science education research. The first implication focuses on the need for further exploration of prospective science teachers' modeling understandings. The second focuses on the need for longitudinal studies to examine the development of prospective science teachers' modeling understandings. The third implication centers on the need for further inquiry into the relationship between domain-specific knowledge and understandings about models and modeling.

### 7.2.1 Need for further exploration of prospective science teachers' modeling understandings

I have been able to describe the modeling understandings of eight prospective science teachers. This sample was appropriate for examining their understandings in the context of their participation in an instructional module that included building and testing dynamic computer models of pond ecosystems. Extending my results to other prospective teachers in other contexts was not the purpose of this research per se. Still, the topic of prospective teachers' views of models and modeling were essentially uncharted waters prior to the present study. Only two other studies exist that report on the examination of prospective teachers' understandings, Smit and Finegold (1995) and De Jong and van Driel (2001). It is possible that additional nuances and differences among key players could be identified through the examination of a larger sample of prospective teachers. In addition, questions have been raised that indicate a need for additional studies of prospective science teachers' understandings. For instance, Harrison (2001a), van Driel and Verloop (1999a), and Justi and Gilbert (in press) all noted differences in modeling understandings among inservice teachers of different science disciplines. The sample size of eight made such comparisons among the disciplines inappropriate in the present study.

The results of my study also suggest a potential need for slightly different approaches. One of the strengths of my study was that I examined articulated (i.e. stated in the spoken or written word) and non-articulated understandings. However, a limitation was that the non-articulated understandings, the models and modeling strategies, represented the combined effort of a pair of prospective teachers. I learned what they could explain in words about models and modeling individually but not how they as individuals put that knowledge to use building and testing models. Having individuals build and test models could provide additional insight. The research protocol would need to be different and might consist of one modeler working at a computer with a researcher on hand to ask them to explain their decisions. I did some questioning of this type in the present study but it was well after the modeling sessions. In most instances the prospective teachers had difficulties remembering decisions they had made weeks before. The process-video data did not reveal information about why they chose to employ certain strategies at certain times. This may also suggest the need to conduct the interviews closer to the time when the modeling actually occurred.

**7.2.2 Need for longitudinal studies of prospective teachers' understandings**

I have described prospective science teachers initial modeling understandings and how they changed. I found that their understandings of various dimensions were not necessarily at the same level of sophistication. I also learned that they are not likely to have sophisticated understandings in one dimension and naïve understandings in another. The question of how prospective teachers' understandings of models and modeling develop arises. The duration of the modeling module was relatively short. This made examining the development of the prospective teachers' understandings difficult. It is conceivable that understanding in one dimension or aspects of various understandings could potentially be linchpins or catalysts to the development of understandings in others. Therefore, there is an additional need for longitudinal studies, or studies aimed at uncovering the development of modeling understandings.

Longitudinal studies are also needed to track prospective teachers' understandings about and abilities to do inquiry and how they develop from content preparation to teacher preparation to the induction period of their professional development. Each of these three phases of teacher development provides fertile problem space related to teacher subject-matter knowledge. Questions related to content preparation include examining the kinds of experiences that prompted some prospective teachers to have more sophisticated views than others and related to differences in views of teachers in different subject areas, exploring the nature and sources of those differences. Regarding teacher preparation, little is known about supporting prospective teachers in developing pedagogical content knowledge (Shulman, 1986, 1987) for scientific inquiry. Furthermore, discussions of what prospective teachers know and how they come to know it are purely academic if we do not study how that knowledge manifests itself in the classroom later. One interesting occurrence in my study was when Matt attempted to include instruction about models in his own teaching. He was having an early field experience concurrent with his participation in the modeling module. Having a window into how a prospective teacher made sense of the module in his own teaching was interesting and informative. It enabled me to identify limitations in Matt's knowledge that may not have come to light by merely discussing the events of the module.

### 7.2.3 Need for studies of the relationship between modeling and domain-specific knowledge

One interesting question my study raises is 'What is the relationship between prospective teachers' domain-specific knowledge of pond ecosystems and their understandings of models and modeling?' My results were inconclusive in this regard. It would appear that to be a successful modeler, one would need fairly sophisticated knowledge of each. The answer to this question has implications for science teaching and learning in terms of designing the most effective sequences of learning experiences. Contemporary views on cognition suggest that learning is situated which implies that the context in which modeling takes place would strongly influence what is learned. It is conceivable that modeling phenomena that you are familiar with, if that is the more important knowledge domain of the two, would lead to more successful modeling and thus better learning about modeling. On the other hand, having a sophisticated understanding of the phenomenon being modeled may decrease the authenticity of the modeling since modeling is most effective when the system under study is not understood. Sophisticated understanding of modeling would equip the learner with a strategy for learning about the phenomenon in question and make the experience more scientifically authentic. Such interesting questions suggest a need for additional study into this complex relationship.

### 7.3 Implications for Science Teacher Education

This section discusses implications for science teacher education. The first implication focuses on the need for opportunities for prospective teachers to reason like scientists. The second focuses on the need for prospective teachers to examine the role of the learner.

#### 7.3.1 Need for experiences reasoning like scientists

The results of my study suggest that prospective teachers need more experiences engaging in certain scientific practices. I do not speak here of being able to measure accurately or being able to design an experiment. Instead, I am referring to the shift recommended in the National Science Education Standards from science as exploration and experiment to science as argument and explanation (NRC, 2000, p.113). Specifically, they need experiences engaging in the same kind of reasoning that scientists employ. Some phenomena cannot be examined directly and in many instances scientists are forced to use model-based reasoning to develop explanations. It was revealed in the interviews that most of the prospective teachers had few, if any memorable experiences with models. In most instances those experiences were to build models that looked like their targets in order to learn about the structure of the target. In many of these instances, the model was being used like a photograph except an additional level of abstraction had been added by having marshmallows represent electrons in an atom or Jello as cytoplasm in a cell. Models can yield important visual insight but the true power of models is to encompass the modeler's ideas in a form that permits testing against the behavior of the target. The prospective teachers do not appear to have ever had experiences modeling in this way. It is difficult to conceive of science teachers teaching science as inquiry when they themselves have little or no experience *doing* science. Therefore, they need experiences engaging in scientific inquiry.

Modeling is an absolutely essential aspect of the scientific endeavor but it appears that traditional science teacher preparation in their subject areas does not include opportunities to engage in scientific modeling and use models as scientists use them. Traditional science teacher preparation in science often consists of the mastery of fact-dominated information and conveys an image of scientific inquiry that is not consistent with actual scientific practice (R. D. Anderson & Mitchener, 1994). Pursuant to the recommendation to provide opportunities for prospective teachers to engage in modeling activities, they should have opportunities in their college-level science courses to develop arguments, explanations and models from evidence (NRC, 1996). I have shown that more-scientific understandings can be developed in a relatively short amount of time. It is possible that expert-like understandings could be developed through numerous experiences with models in all science subject areas.

**7.3.2 Need for experiences learning science as inquiry**

The prospective teachers neglected certain relationships in their models. It is unclear if this was due to limited modeling understandings, domain-specific knowledge of pond ecosystems, or some combination of the two. What is certain is that some of them became frustrated by not knowing certain relationships. This suggests that prospective teachers may be frustrated by learning science and about science in the manner I am recommending. Learning involves making oneself vulnerable and taking risks (Bransford et al., 2000). In most cases they have experienced science facts but not science itself. Learning science as inquiry is more cognitively demanding than being passive receivers of information. The frustration prospective teachers are likely to feel when confronted with actually developing an explanation or argument from evidence can become an important opportunity for them to consider the role of the learner. If they never come to terms with their own frustrations with learning science as inquiry, they are unlikely to attempt to engage students in such activities, as they become teachers themselves.

### 7.4 Implications for Science Teaching and Learning

This section discusses implications for science teaching and learning. The first implication focuses on the need for modeling in the curriculum. The second focuses on the need for the continued development of models for teaching about scientific models and modeling.

#### 7.4.1 Need for modeling in the curriculum

Modeling should assume the same ubiquitous status in science education that it has in the development of scientific knowledge. The act of building models, or modeling is a way of thinking called model-based reasoning. Modeling is a means though which scientists develop knowledge about the world. It has been shown that modeling provides opportunities for students to demonstrate important thinking strategies (Stratford, 1995). It has also been shown that modeling can support students learning science subject matter (Harrison & Treagust, 2000; Schwarz & White, 1998; Wells et al., 1995), and in learning *about* science (Schwarz & White, 1998; Wisnudel-Spitulnik et al., 1999).

As discussed above, modeling can provide a fertile context for learning science content and about the nature of science and scientific inquiry. Scientists engage in modeling in the development knowledge about many natural phenomena. Students too can learn science content by embodying their ideas about a phenomenon in a model and testing against observations of that phenomenon. A modeling approach is both pedagogically and scientifically sound. My research supports Abd-El-Khalick and Lederman's suggestions regarding explicit attention being directed to issues related to the nature of science and scientific inquiry (2000). School science teachers, in this era of high-stakes testing, may be reticent to take the time to teach about the nature of science and scientific inquiry. They may be more willing to do so if they can be convinced that there are means for supporting the development of domain-specific and inquiry understandings simultaneously as is possible when students engage in modeling.

**7.4.2 Need for the continued development of *models for teaching* about scientific modeling**

I now have a depth of experience in this endeavor and can make recommendations. Most of theses recommendations relate to how I would change instruction were I to "do it all again." First, measures could be taken to ensure the prospective teachers employ sound modeling strategies. One measure would be to encourage them to test their models often. The results of this study suggest that the one pair who did run multiple tests of their model while building relationships built a far superior model to those who did little testing. Second, knowledge of the software is crucial when time is a concern because it is easy to get bogged down trouble-shooting software and in a large, busy classroom it can be difficult for teachers to provide necessary technical support when it is needed.

Prospective teachers are an interesting group in that they are teachers in some ways and students in others. They are therefore subject to some of the trappings that befall students regarding grades. A shortfall of the instructional design of the module was evaluation. I did not "grade" the prospective teachers' models. As a result they may not have put forth the same amount of effort into building and testing their models that they might have had their course grade been at least somewhat dependent on the content and structure of their models. In future efforts of this nature I will hold them accountable in some way for producing sound models. Obviously I will need to provide additional instructional support as well.

While listening to the audiotaped portion of the process video data I found myself wishing I could have been working with certain pairs at the time they made certain comments. I sense that if I could have supplied some explicit instruction at certain instances that more sophisticated modeling understandings may have been developed. In one instance Kate and Matt expressed concern over the fact that they decided what went into their model and therefore they determined how the model behaves. This is quite true. I would have like to speak with them at that instant to help them to the realization that the model actually embodies their ideas and therefore becomes a vehicle for testing those ideas. I could have also prompted them to think about how scientists use models in a similar way when the phenomenon is inaccessible for direct observation. My desire to provide "individual" instruction at key moments suggests that I should require and find ways to promote more explicit reflection about the act of modeling while the prospective teachers are actually engaged in modeling.

Finally, I feel I can make two important recommendations regarding the context I chose for the module. A pond ecosystem was chosen because I assumed it would be familiar to the prospective teachers and because two ponds were quite accessible to us. However, the accessibility of the ponds may have actually inhibited the prospective teachers from realizing the power of modeling. One could argue that modeling the pond was un-necessary because we could return to the pond again and again. A different phenomenon, one that was inaccessible for direct observation such as an event that happened in the distant past, may have been more useful for convincing the prospective teachers of the utility of modeling. Also, we incorporated modeling and field study to reinforce the connection between building models and revising them in light of their agreement with available data. However, we used snapshots of the data. It may have been better to have students collect or by some other means access more data related to the phenomenon under study. The snapshots of two ponds may not have been sufficient to permit the prospective teachers to understand the intellectual rigor associated with modeling. They may have been forced to engage in more iterative cycles of building, testing, and revising for instance if they were trying get their model to behave like a pond behaves throughout the course of a day.

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## APPENDIX A



## INFORMED CONSENT FORM FOR BEHAVIORAL SOCIAL SCIENCE RESEARCH

The Pennsylvania State University

Title of Project: **Investigating the Use of Technology Tools to Enhance Prospective Science Teachers' Understanding of the Role of Models and Modeling in Science**

Principal Investigator: Michael J. Cullin, grad. student, Curriculum & Instruction
Other Investigator(s): Barbara A. Crawford, PhD
Carla Zembal-Saul, PhD
Roy Boyle, grad. student, Curriculum & Instruction

1 **This section provides an explanation of the study in which you will be participating:**

A Purpose of the Study: The purpose of this research is to explore the understandings about the role of models and modeling in science of prospective science teachers and the effect of instruction and modeling experiences on those understandings.

B If you agree to participate in the study, the investigators will keep electronic copies of selected assignments for further examination. In addition, your participation may involve two audiotaped interviews and the videotaping of your use of specific technology tools throughout the semester.

C With the exception of the interviews, your participation in the study will not extend beyond your normal involvement in the course. That is, there will be no additional requirements associated with course projects/assignments if you agree to participate in the study.

D If you do not want to participate in this research, you will still be required to complete course projects/assignments; however, your work will not be used in the study.

E This study will involve audio and video recording. Only the investigators will have access to these tapes. All audio and video tapes will be destroyed after a period of 5 years.

**2 This section describes your rights as a research participant:**

A You may ask any questions about the research procedures and these questions will be answered. Further questions should be directed to Michael J. Cullin

B Your participation in this research is confidential. Only the person in charge and other investigators on this project will have access to your identity and to information that can be associated with your identity. In the event of publication or presentation of this research, no personally identifying information will be disclosed.



C If you decide not to participate, it will not be disclosed to the person responsible for grading until after grades have been submitted at the end of the semester.

D Your participation is voluntary. You are free to stop participating at any time or to decline to answer specific questions without penalty.

E This study involves only minimal risk, that is, no risk to your physical or mental health beyond those encountered in the normal course of everyday life.

**3 This section indicates that you are giving your informed consent to participate in the research:**

**Participant:**

I agree to participate in a systematic investigation of the understandings of the role of models and modeling in science as an authorized part of the education and research program of The Pennsylvania State University.

I understand the information given to me and have received answers to any questions I may have had about the research procedure. I understand and agree to the conditions of this study as described.

To the best of my knowledge, I have no physical or mental illnesses/difficulties that would increase the risk to me by participating in this study.

I understand that I will receive no compensation for participating, and that my grade in the course will not be altered by my participation.

I understand that my participation this research is voluntary, and that I may withdraw from the study at any time by notifying the person in charge.

I understand that I will receive a signed copy of this consent form.

______________________________ ________________

Participant Signature Date

**Researcher:**

I, the undersigned, verify that the above informed consent procedure has been followed, and that I have answered any questions from the participant above as fully responsible.

______________________________ ________________

Investigator Signature Date

## APPENDIX B

### SCIED 410 Modeling Questionnaire

**Name:** **date:** **subject area:**

1. What is a scientific model?

2. Describe a model used by scientists in your field of science. What is the purpose of this model?

3. When making a scientific model, what do you have to keep in mind or think about?

4. How close does a scientific model have to be to the thing itself?

5. Would a scientist ever change a model? If so, why? If not, why not?

6. Can a scientist have more than one model for the same thing? If so, why? If not, why not?

7. Is teaching about models important in your area of science? Why or why not?

8. Do you intend to teach students about models and modeling? Why or why not?

# APPENDIX C

## Timeline – Instructional Sequence and Data Collection

| Date | Prior to 3/11 | 3/28 Session 1 | 4/2 Session 2 | 4/4 Session 3 | 4/11 Session 4 | 4/16 Session 5 | 4/18 Session 6 | 4/23 Session 7 | 4/25 |
|---|---|---|---|---|---|---|---|---|---|
| **Activities** | | Intro to pond ecology<br><br>Intro to guiding question | Intro to sci. models<br><br>Phys. data collection techniques<br><br>Bio-div. data collection techniques | Data collection at Tait Farm pond #1 (wooded) | Intro to Model-It<br><br>Build/test pond models<br><br>Make predict. Re:driving question | Data collection at Tait Farm pond #2 (non-wooded)<br><br>Data collection at Tait Farm pond #1 (wooded) | Discussion of pond experience<br><br>Model revision<br><br>Using model to conduct an experiment | Model present.<br><br>Discussion of models and modeling in science | |
| **Data Collected** | Questionn. #1 – pre (16 partic.) | 4 sections of readings assigned<br><br>VT class session<br><br>Instructor's Reflections | PSTs models from their subj. area assignment<br><br>VT class session<br><br>PST group generated lists of common sci. modeling character.<br><br>My overhead of sci. model Character.<br><br>Questionn. #2 – (a) (16 partic.)<br><br>Instructor's Reflections | Data sheets<br><br>Instructor's Reflections<br><br>Sample data | Process video – 4 pairs<br><br>Completed models (8 pairs)<br><br>Questionn. #2 – (b) (16 partic.)<br><br>VT class session<br><br>Instructor's Reflections<br><br>PSTs relation. assignment | Sample data<br><br>Instructor's reflections | Interview with Taits from 4/16<br><br>Process video – 4 pairs<br><br>Completed models (8 pairs)<br><br>Questionn. #2 – (c) (15 part. – 1 absent)<br><br>VT class session<br><br>Instructor's Reflections | VT of presentatio ns and class discussion<br><br>Letter from Russell Hulse<br><br>Instructor's Reflections | Questionn. #1 – post (16 partic.) |

| | | |
|---|---|---|
| Pre-interviews conducted between 3/28 and 4/1 (8 participants – same as 4 pairs for process video) | | Post-interviews conducted between 4/26 – 5/2 (8 participants – same as 4 pairs for process video) |

## APPENDIX D

### Dimensions of Modeling Understanding

| Dimension | Limited | Pre-Scientific | Emerging Scientific | Scientific |
|---|---|---|---|---|
| | 1 | 2 | 3 | 4 |
| **Purpose of Models** | Teaching purposes. Used as an aid in making an explanation to someone else. | Used to think with. Something to help visualization while user is thinking about phenomenon. Used as an aid in formulating an explanation. | Test out unsafe or potentially destructive things. Explore "what if?" scenarios. Model is used in place of target. | A model is a research tool that is used to obtain information about a target that cannot be observed directly. A model bears certain analogies to the target, thus enabling the researcher to derive hypotheses from the model that may be tested while studying the target. Testing these hypotheses produces new information about the target. (Van Driel and Verloop) In other words, getting the model to behave like the target may yield insight into the behavior of the model. |
| **Building Models** | Model is designed to "get the point across." | Connection between modeler's ideas and the model... what the modeler thinks rather than what they are trying to get across. | Get the model to behave like the target... would result in different relationships being built into the model. | A model is developed through an iterative process, in which empirical data with respect to the target may lead to a revision of the model, while in a following step the model is tested by further study of the target. (Van Driel and Verloop) Ultimately the goal is to get the model to behave like the target. |
| **Changing Models** | Models are not changed | A model is changed when new discoveries are made | A model is changed when it doesn't behave like the modeler wants it to | Models are temporary in nature. (Smit and Finegold) A model is changed when its behavior is not in agreement with observations of the target. |
| **Multiple Models for the Same Thing** | Different models are the result of different learning modalities, educational levels, audiences, or forms. | Different models result from different modeler's ideas OR from focusing on different aspects of the target | Different modeler's ideas represent competing models or theories for explaining the target phenomenon | Different models for the same phenomenon result from different assumptions about the target or addressing different aspects of the target. (Grosslight et al) Someone at this level would know that multiple models may represent competing theories/explanations about the target OR focus on different aspects of the target. |
| **Validating Models** | No reference. | Models are validated by the scientific community (an external authority) | Models are validated by comparing the behavior of the model with the behavior of the target | Models can be checked or verified by comparing the results obtained by manipulating the model to observations obtained in the real world. . (Grosslight et al) If the model behaves like the target you may know how the target behaves. If the model does not behave like the target you probably have made an incorrect assumption about the behavior of the target and therefore your model should be changed. |

# APPENDIX E

## Model Scoring Rubric

**Quantitative Aspects of the Model** __________

| | | Multiplier for weighting relative difficulty | |
|---|---|---|---|
| Number of objects | | X 1 | |
| Number of Variables | | X 2 | |
| Number of Relationships | | X 3 | |
| Variables with Multiple Relationships | | X 1 | |

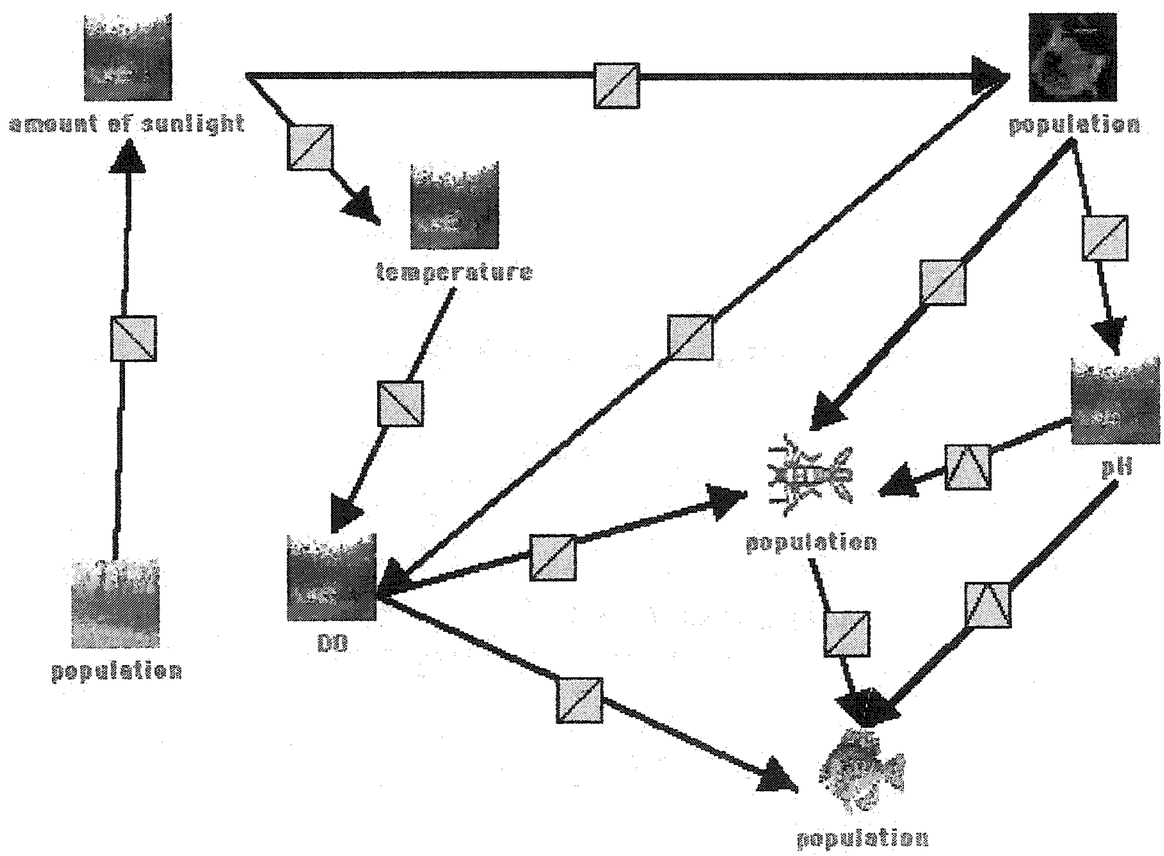
**Qualitative Aspects of the Model** __________

| **Critical Objects** | | **Critical Variables** | | | |
|---|---|---|---|---|---|
| Pond | | Temperature | | | |
| | | Dissolved $O_2$ | | | |
| | | Amount of sunlight | | | |
| | | pH | | | |
| Trees | | Population | | Others | |
| Aquatic plants | | Population | | Others | |
| Fish | | Population | | Others | |
| Macroinvertebrates | | Population | | Others | |
| Other(s) | | | | | |

| **Critical Relationships** | **Correct Relationship** | **Correct Direction** |
|---|---|---|
| Sunlight and aquatic plants | | |
| Trees and Sunlight | | |
| Sunlight and pond temperature | | |
| Temperature and dissolved oxygen | | |
| Dissolved oxygen and fish | | |
| Dissolved oxygen and macroinvertebrates | | |
| pH and fish | | |
| pH and macroinvertebrates | | |
| Aquatic plants and dissolved oxygen | | |
| Aquatic plants and pH | | |
| Food chain | | |
| • Fish eat macroinvertebrates (bonus for other correct relationships) | | |
| • macroinvertebrates eat algae (bonus for other correct relationships) | | |
| Other(s) | | |

## APPENDIX F

## A "Standard" Pond Model Built in MODEL-IT



## APPENDIX G

### Scored Standard Model

**Quantitative Aspects of the Model ___45_______**

| | | Multiplier for weighting relative difficulty | |
|---|---|---|---|
| Number of objects | **5** | X 1 | **5** |
| Number of Variables | **7** | X 2 | **14** |
| Number of Relationships | **8** | X 3 | **24** |
| Variables with Multiple Relationships | **2** | X 1 | **2** |

**Qualitative Aspects of the Model ____37______**

| **Critical Objects** | | **Critical Variables** | | | |
|---|---|---|---|---|---|
| Pond | **1** | Temperature | | | **1** |
| | | Dissolved $O_2$ | | | **1** |
| | | Amount of sunlight | | | **1** |
| | | pH | | | **1** |
| Trees | **1** | Population | **1** | Others | |
| Aquatic plants | **1** | Population | **1** | Others | |
| Fish | **1** | Population | **1** | Others | |
| Macroinvertebrates | **1** | Population | **1** | Others | |
| Other(s) | | | | | |

| **Critical Relationships** | **Correct Relationship** | **Correct Direction** |
|---|---|---|
| Sunlight and aquatic plants | **1** | **1** |
| Trees and Sunlight | **1** | **1** |
| Sunlight and pond temperature | **1** | **1** |
| Temperature and dissolved oxygen | **1** | **1** |
| Dissolved oxygen and fish | **1** | **1** |
| Dissolved oxygen and macroinvertebrates | **1** | **1** |
| pH and fish | **1** | **1** |
| pH and macroinvertebrates | **1** | **1** |
| Aquatic plants and dissolved oxygen | **1** | **1** |
| Aquatic plants and pH | **1** | **1** |
| Food chain | | |
| • Fish eat macroinvertebrates (bonus for other correct relationships) | **1** | **1** |
| • macroinvertebrates eat algae (bonus for other correct relationships) | **1** | **1** |
| Other(s) | | |

# Curriculum Vitae

Michael J. Cullin
mcullin@lhup.edu

303A Ulmer
Lock Haven University
Lock Haven, PA 17745
(570) 893-2813

620 Berkshire Dr.
State College, PA 16803
(814) 235-7286

## EDUCATION

| | |
|---|---|
| PhD. | The Pennsylvania State University College of Education; 2004. Curriculum and Instruction (Science Education). Dissertation: "Examining Prospective Science Teachers' Understandings of the Role of Models and Modeling in Science Within the Context of Building and Testing Computer Models of Pond Ecosystems" |
| 1996-98 | Graduate coursework, primarily in the area of Educational Technology (East Stroudsburg University, St. Joseph's University, Gratz College, University of Dallas, and Wilkes University) |
| M.Ed. | East Stroudsburg University, 1996 |
| B.S. | Kutztown University, 1988. Major in Physics. Secondary physics teaching certification (Pennsylvania), 1989. |

## POSITIONS

| | |
|---|---|
| 2003 – present | Assistant Professor of Physics and Science Education Program Coordinator, Lock Haven University (General Physics Lab, Science for the Elementary Grades, Student Teaching Supervision and Practicum) |
| 1992-2003 | Physics Teacher, Bethlehem Area School District, Bethlehem, Pennsylvania (Advanced Placement Physics, Physics, Principles of Technology). |

## PUBLICATIONS

### Accepted

Crawford, B.A. & Cullin, M.J. (accepted). Supporting Prospective Teachers' Conceptions of Modelling in Science. International Journal of Science Education.

### Published

Cullin, M.J., & Crawford, B. A. (2003). Using technology to support prospective science teachers in learning and teaching about scientific models . *Contemporary Issues in Technology and Teacher Education.* *2*(4). Available: http://www.citejournal.org/vol2/iss4/science/article1.cfm