This article presents efforts to support prospective secondary science teachers in learning and teaching about scientific models and the impact of those efforts on their understandings. The role played by scientific models is an often under-emphasized aspect of the conduct of science associated with an understanding of the nature of science and scientific inquiry. The National Science Education Standards present a vision of what students need to know, understand, and be able to do to be scientifically literate at different grade levels (National Research Council [NRC], 1995). Among the recommendations regarding scientific inquiry, references are made to the use of models in learning science. For example, it is recommended 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).
The vision of the National Science Education Standards, if it is to be realized, will require science teachers to be knowledgeable in many aspects of scientific inquiry including the role of models and modeling. Justi and Gilbert (2001, pp. 9-10) suggested that 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. There appears to be little guidance from the literature specifically related to prospective teachers’ understandings of and their use of models. 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 (Anderson & Mitchener, 1994). More often than not, novice teachers learn much of the science they later teach during the early years of their careers, when the primary resource for enhancing their understandings is a textbook. Unfortunately, many science textbooks, including those that present scientific models, fail to identify them as such (Harrison, 2001). More importantly, due to the nature of their subject matter preparation, prospective science teachers are unlikely to experience using models as a tool for learning about nature. Instead, what are termed “science process skills” are typically developed through “cookbook,” verification-type laboratory activities. The question emerged, “To what extent do prospective science teachers know about how scientists use models and in what ways are prospective science teachers prepared to engage their own students in the modeling of natural phenomena?” The authors endeavored to engage prospective science teachers as learners in a modeling experience and provide them the opportunity to apply the knowledge gained in these experiences to the design of instruction for their own future students.

THEORETICAL FRAMEWORK

It has been suggested that a better understanding of scientists and the scientific community will enhance an understanding of science’s strengths and limitations, interest in science and science classes, social decision making, instructional delivery, and the learning of science content (McComas, Clough, & Almazroa, 1998). Models are integral to thinking and working scientifically because models are science’s products, methods, and its major learning and teaching tools (Gilbert, 1993). A model of something is a simplified imitation of it that we hope can help us understand it better.
Much has been written about the role of models and modeling in science from a history and philosophy of science viewpoint (Black, 1962; Giere, 1990; Hesse, 1966). It has even been suggested that both the processes and products of science are well portrayed by defining science as a process of constructing predictive conceptual models (Gilbert, 1991). For the scientist, a model is a tool used to learn about some object or phenomenon, referred to as a target (Dunbar, 1999), when that target is in some way inaccessible or at least inconveniently accessible. By learning about the model, which has certain attributes in common with the target, the scientist can learn about the target.

Recently there has been interest in models and modeling in regard to science education as evidenced by entire issues of science education journals being dedicated to the subject (e.g., the November 1991 issue of the Journal of Research in Science Teaching and the September 2000 issue of the International Journal of Science Education). However, very little has been written about inservice and prospective science teachers’ knowledge about models and modeling in science. Van Driel and Verloop (1999) 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. The criteria used by the science teachers for deciding what qualifies as a model varied considerably. Yet, they rarely mentioned many important functions and characteristics of models. For example, selected 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 (Van Dreil & Verloop, 1999).

Smit and Finegold (1995) studied prospective physical science teachers’ perceptions of models in general and models specific to optical phenomena. 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 (Smit & Finegold, 1995). 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.
Research presented at a recent National Association of Research in Science Teaching conference shed some light on teachers’ understanding about scientific models. These papers are possibly indicative of a natural trend to move beyond simply defining models solely on how philosophers of science might define them to the context of teachers’ perceptions and use of models. Both Harrison (2001) and De Jong and Van Driel (2001) explored inservice and prospective science teachers’ pedagogical content knowledge of models and modeling. The views of models possessed by the experienced teachers interviewed and observed by Harrison can be characterized as rich, comprehensive, creative, and well aligned with recommendations in the literature when considered as a group. When considered individually, the teachers’ knowledge appears insufficient for engaging students in scientific modeling and teaching them about scientific models. There is an important distinction between a model used by a teacher for explanatory purposes and a model used by a learner as a thinking tool to test ideas and predictions. Only 5 of the 22 teachers expressed the belief that models could be used as thinking tools. It is probably no coincidence that these five teachers possessed a depth of knowledge considered to be more advanced conceptions of models and modeling (Grosslight, Unger, Jay, & Smith, 1991).

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 postgraduate teacher education programs at the Institutes of Education of Utrecht University and Leiden University. The prospective science teachers in this study all held masters of science degrees in chemistry. Yet, 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 (De Jong & Van Dreil, 2001). Of all of the studies reviewed thus far, De Jong and Van Driel (2001) represented the only study in which a stated goal was to measure and/or describe change resulting from some form of intervention. This study was set in the context of a course 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 ongoing preservice teaching experiences. Yet, the apparent lack of improvement in the prospective science teachers’ knowledge about models in science indicates the need for alternative experiences to confront prior understandings.
From a review of the literature, it becomes apparent that science teachers, both in-service and prospective, do not generally possess adequate knowledge about role of models and modeling in science. Each study based its claims on a backdrop of contemporary philosophy of science. The present study presents an interesting alternative to the studies previously reviewed in that it seeks to describe the effects of an instructional intervention on prospective science teachers’ understandings of, and intentions to, teach about scientific models and modeling through the analysis of a number of data sources. This study seeks to contribute to this literature base by examining changes in prospective science teachers’ knowledge of the importance of scientific modeling by engaging them in scientific modeling through building and testing dynamic computer models. The purpose of this study is to (a) design instruction around the dynamic modeling software Model-It and; (b) investigate the impact of this instruction on prospective science teachers’ understandings of the role of models and modeling in science. Specifically, the research was guided by the following questions: (a) What do prospective science teachers understand about the importance of models and modeling in science? and (b) How do their understandings change as a result of their participation in a modeling experience in an undergraduate science teaching methods course?

CONTEXT AND METHODS

Context

The authors designed an instructional module to be taught during part of an advanced science teaching methods course for secondary science teachers. The module focused on scientists’ use of models using as the centerpiece the dynamic systems modeling software Model-It, developed at the University of Michigan’s Center for Highly Interactive Computing in Education - (HI-CE, www.hi-ce.org). There is a trial version of this software downloadable from the Web (http://goknow.com/modelit.htm). The authors planned to engage the prospective secondary science teachers in a series of modeling-related activities. The instructional experiences included students’ investigating real-world phenomena, and then designing, building, and testing computer models, related to the real-world investigations.
The main purpose of the activities was to enhance prospective secondary science teachers’ knowledge of the importance of modeling in science. The two main tasks associated with scientific modeling are model construction and model verification. *Model-It* is designed to support students’ learning about modeling: acquiring strategies for constructing and verifying models and developing skills to plan, predict, and debug them (Jackson, Stratford, Kracjik, & Soloway, 1995). Learners first build qualitative models, and then move to more quantitative models as they develop the necessary expertise. To support students in model construction, *Model-It* assists learners in making the transition from what they already know of the world to computerized model representations and establishes a bridge between simple and more expert-like representations (Jackson et al., 1995).

**Participants**

Fourteen prospective science students participated in the study. Of the 14, six were seeking certification in biology and/or general science, four in physics, three in earth/space science, and one in chemistry. The second author served as lead instructor in the course, the third of three sequenced methods courses for secondary science teachers, and collaborated with the first author on the design of the research. The course incorporates theory and practice associated with science learning and teaching in school classroom settings. Prospective science teachers concurrently enroll in the theory-based methods course and a teaching practicum involving an increasing amount of time in science classrooms. Course assignments are designed to support and take advantage of the rich authentic experiences in the practicum.

**Data Collection Methods**

The instructional goal was to engage the prospective science teachers in an extended inquiry, have them build computer models using *Model-It*, and then have them begin to consider how they might engage their own future students in modeling activities. To document the experience the authors videotaped all relevant class sessions and used process video techniques to capture video of the computer monitor while using the software and audio...
recordings of the participants while building and testing models. Prospective science teachers completed pre and postmodeling experience questionnaires, and the authors interviewed representative members of the class about the experience and their responses to the questionnaires. Finally, the prospective science teachers wrote a reflective paper about the modeling experience and designed a unit of study in which middle and high school students would be engaged in modeling activities.

Grosslight, Unger, Jay, and Smith (1991) developed a classification scheme of modeling conceptions in a study of middle and high school science students and experts. Since our prospective science teachers would someday be responsible for portraying and conveying expert-like conceptions of the role of models and modeling in science their understandings were compared to those elicited from subjects in the Grosslight et al. study. Therefore, a questionnaire was developed using similar questions. The questionnaire was developed in collaboration with researchers from the University of Michigan doing similar research on students’ understandings of the role of models and modeling in science. 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?

Two additional questions were added, designed to elicit the prospective science teachers’ views and intentions regarding teaching about scientific models and modeling:

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 research protocol used by Grosslight et al. employed semi-structured interviews, whereas, in this study the prospective science teachers responded to pre and post-instruction questionnaires and the responses of representative participants were further explored through semi-structured interviews.

**Data Analysis**

The data analyses discussed here are a portion of a larger study in which the participants’ uses of the software scaffolds in *Model-It* were also being examined. The prospective science teachers prior to the modeling experience completed the preinstruction questionnaires by way of paper and pencil. The first author later typed these responses into a word processing document. The prospective science teachers completed the postquestionnaires electronically. For the purpose of contrasts and comparisons across participants, responses to the same items on the pre and postquestionnaires were arranged in tables (Miles & Huberman, 1994). This aided the identification of salient themes, recurring ideas and/or language, and patterns of belief (Marshall & Rossman, 1999). Postinstruction interviews were transcribed, and these transcriptions, reflective writing assignments, and unit plans were examined to validate and substantiate findings from the analysis of the pre and postquestionnaires. In addition to assessing understandings, the authors looked for prospective science teachers’ perceived importance of and intentions to teach about models and modeling.

**FINDINGS**

The findings of the study are organized around the research questions and the emergent themes and patterns associated with each question discussed in turn.

*What do prospective science teachers understand about the importance of models and modeling in science?*
Scientific inquiry has been defined as the methods, activities, and progression of such that lead to the acquisition and development of scientific knowledge (Schwartz, Lederman, & Crawford, 2000). Scientific modeling is an essential component of scientific inquiry. A model of something is a simplified imitation of it that we hope can help us understand it better (AAAS, 1989, p. 168). In terms of the prospective science teachers’ knowledge of the role of models and modeling in science, it was found that most of them could be classified as Level II modelers based on the classification scheme developed by Grosslight et al. (1991). Level II modelers can distinguish between ideas and/or purposes motivating a model and the model itself, and realize that the purpose of a model dictates some aspect of the form of the model. They also recognize how experimental evidence might show that some aspect of a model may be wrong and needs to be changed, and they imagine in a limited way how a model might have to be revised. Unfortunately, level II modelers see models as representations of real-world objects or events and not as representations of ideas about real-world objects or events. They also see the use of different models as that of capturing different spatio-temporal views of the object rather than different theoretical views.

One aspect of level II modelers, reported by Grosslight et al. (1991) and quite prominent among the participants in this study was the view that models are a means to communicate information about real-world events rather than as a means to test and develop ideas or theories about the world. Analysis of the survey responses showed that the prospective science teachers viewed scientific models as a representation of some object or phenomena (the target) that is used by “someone who understands” the target to explain it to “someone who doesn’t.” The following responses are representative the responses of many of the prospective science teachers:

A model is another way to present information so that people can gain a deeper understanding. (Bonnie-BIO, presurvey)

A representation of some object or process that is used to explain something. (Paul-PHYS, presurvey)

In responding to the questions “What is a scientific model?” and “What is the purpose of a scientific model?” the prospective science teachers made numerous references to models being used for pedagogical purposes:
A scientific model is a visual learning aid of something in life that would be hard to use the actual thing in the classroom. (Claire-BIO, presurvey)

A way to show students how a scientific concept works. (Michelle-BIO/GEN SCI, presurvey)

Models as pedagogical tools appeared to characterize the prospective science teachers’ initial conceptions of scientific models even when some of the questions designed to elicit their understanding of how models are built and used by scientists were examined. This is evidenced by some of the responses to the question “When making a model, what do you have to keep in mind?”

What the people already know and what you want them to learn from the model. (Bonnie-BIO, presurvey)

The object or principle you want to explain. (Nick- EARTH/SPACE, presurvey)

This theme is echoed in some of the prospective science teachers’ responses to the question “How close does a model have to be to thing itself?”

Close but not as close that you could just describe the real thing. Different levels for different learners. (Michelle-BIO/GEN SCI, presurvey)

That depends on what it is being used for, a model of an atom in third grade might be (sketched single electron orbiting large nucleus) where in 12th-grade (sketched electron cloud) (Paul-PHYS, presurvey)

With regard to the idea of multiple models, the prospective science teachers were sure that scientists change models and can have more than one model for the same target. They appeared to hold the idea that a model is changed based on “new information.” The prospective teachers never identified the role models play in the development of “new information.” The understanding of scientific models that emerged is one of a final form device used for communicating the explanation of something that is already understood:
Yes, they (scientists) are always making new discoveries. They better change the models to better represent the truth. (Claire - BIO, presurvey)

Of course (scientists would change a model), to change the way the thing is represent or to portray it through a different medium (Michelle-BIO/GEN SCI, presurvey)

Yes, different models can present the same information in a different way. (Bonnie-BIO, presurvey)

Of critical importance to the authors as science teacher educators was to determine the prospective science teachers’ views and intentions regarding teaching about scientific models and modeling. All participants indicated that teaching about models and modeling is important in their area of science. However, the reasons they provided to support the contention that teaching about models is important had little to do with models being central to the scientific endeavor. Instead, most of their justification centered on models enhancing student learning about scientific concepts and phenomena. Again, the participants’ responses emphasized pedagogical aspects of models:

Yes, because models can help the students better understand concepts but the limits must also be explained (Amber-BIO/GEN SCI, presurvey)

Models of the cell, mitosis and many things that are too small to see are very important. They help students conceptualize things. (Claire -BIO, presurvey)

Absolutely (teaching about models is important). There are many times when we model cellular and molecular level events for students to better understand them. Also ecological processes are often better understood though models where students can manipulate numbers and such to see how things work together. (Ellen-BIO/GEN SCI, presurvey)

All of the prospective science teachers indicated that it is important to teach about models and modeling. However, it was interesting to analyze their responses to whether or not they would actually teach about models and modeling in their own future classrooms. Again, their justification was based on the idea that using models in teaching would enhance student learning:
Yes, because I feel it is important for students to have different ways of looking at a concept. (A visual representation). (Lori-EARTH/SPACE)

Yes, because I believe it will be helpful in learning the material. (Amber-BIO/GEN SCI)

Yes, because I feel they are important tools to change misconceptions, allow for revealing of knowledge and great assessment tools. (Michelle-BIO/GEN SCI)

In analyzing the preinstruction survey responses, the prospective science teachers’ understanding of scientific models focused on models that are used to enhance an explanation, either visually or through a tangible representation of the target. There was very little mention of the central role of models in the development of scientific knowledge. The results are not unlike those reported by Grosslight et al., in which the experts tended to talk about models in terms of actively formulating and testing ideas about reality, whereas students tended to point to a more immediate transparency between reality and models (Grosslight et al., 1991). The prospective science teachers distinguished themselves from both the experts and students in their emphasis of the use of models for instructional purposes. Their recognition of the power of models to enhance learning of established scientific ideas is not inaccurate. Yet, we had hoped that by engaging them in modeling activities we might expand their understanding to include an appreciation of the importance of models in the scientific endeavor.

**Research Question #2: How do their understandings change as a result of their participation in a modeling experience in an undergraduate science teaching methods course?**

Analysis of the postsurveys yielded two changes in the prospective science teachers’ understandings. First, there was a change in the description of how a model is used. In the prequestionnaires, the emphasis was on the use of a model by someone who understands the phenomenon in question for explaining the concept to someone who does not. In the post questionnaires the emphasis shifted to the model being used by a “user” to understand the phenomenon.
A scientific model is a visual learning aid of something in life that would be hard to use the actual thing in the classroom. A model can be scaled up or down in size in a way that it would be most useful. (Claire-BIO, presurvey)

A scientific model is a tool or representation of a thing, process, or occurrence that enables the users to better understand the real thing. A model can be much larger or much smaller, faster or slower than what it is modeling. (Claire-BIO, presurvey)

Demonstrating a scientific concept through alternative means. (Nick- EARTH/SPACE, presurvey)

A scientific model is a representation of scientific phenomena in which variables can be manipulated with outcomes congruent with scientific data. Those outcomes can be predicted and analyzed. (Nick- EARTH/SPACE, post-survey)

The second change was particularly encouraging to the authors in light of the decision to use the dynamic computer software Model-It. In the postsurveys, the prospective science teachers used terminology never mentioned in the presurveys. Many of these terms, such the terms variables and relationships, are encountered while building and testing models using Model-It:

Most likely there are assumptions made and so the model may be more of an approximation. (Heather - PHYS, presurvey)

You need to think about the different variables that exist within the system. And then you need to look at how the variables affect one another look at the relationships that exist. You will also need to get information together regarding experiments or research regarding those relationships. (Heather - PHYS, postsurvey)

The prospective science teachers’ were much more focused on how to identify variables and create appropriate relationships as a result of their experience building and testing models using Model-It.

Related to the question to what extent, if any, did their beliefs and intentions to teach about scientific models change as a result of their modeling experience, we were somewhat disappointed in the results. There was
virtually no change in either their beliefs about the importance about teaching about scientific models or their intentions to teach about them. The prospective teachers maintained their belief that models can help students learn science concepts, but they made no references to the central role of models in scientific research or the role of testing ideas.

The purpose of the modeling experience was to effect changes in the prospective science teachers’ knowledge of scientific inquiry. Although there is little evidence to suggest that this happened, there is some evidence of positive changes related to their beliefs and intentions regarding scientific modeling. The prospective science teachers wrote a reflection about the extended inquiry and modeling experiences using the following prompt:

You have been engaged as learners in an inquiry project and a modeling experience. Write an entry in your reflective journals. Include your thoughts on:

1. the importance of involving your students in inquiry;
2. the importance of involving your students in modeling;
3. your level of comfort in designing activities for students in which they would engage in inquiry and modeling; and
4. difficulties you perceive in engaging your own students in inquiry and modeling

Examination of the responses provided encouraging results. Many of the prospective science teachers’ identified the ability of computer models to provide students opportunity to quickly change variables and test the effects:

Therefore being able to change variables and have some control over the model helps students further process the information to make it meaningful. (Ellen-BIO/GEN SCI, reflection)

The students are able to experiment with authentic data in order to see relationships between objects. (Amber-BIO/GEN SCI, reflection)
This suggests a shift from their presurvey statements. There is clearly an increased emphasis on students using models and changing variables. This may indicate a shift toward a more student-centered philosophy.

As novice modelers, the prospective science teachers built relationships while using Model-It largely based on ones they were certain existed. In this sense they created very “safe” models (Figure 1). The classification of the prospective science teachers as level II modelers was confirmed by the failure to acknowledge the model’s utility as an idea-testing tool. While building and testing their own models, many of the prospective science teachers were amazed at the amount of background knowledge needed to expand their models from very basic ones consisting of only a few relationships, to more robust and complicated ones. This revelation seemed to convince many of them that modeling forces the modeler to know and/or learn “their stuff.”

![Figure 1: An example of a model built by two prospective science teachers. The relationships depicted here represent “safe” or well-known relationships as opposed to those that might be indicative of relationships, that when tested, might yield an unknown outcome.](image)
CONCLUSIONS AND IMPLICATIONS FOR SCIENCE TEACHER EDUCATION

The prospective science teachers in this study initially possessed a limited view of the role of models and modeling in science. By engaging prospective teachers in a rich modeling experience building and testing dynamic computer models, the intent was to raise their awareness of the essential role modeling plays in scientific inquiry. In addition the goal was to instill the belief that teaching about scientific models and modeling is important. Unfortunately, there is little evidence to suggest that these prospective science teachers dramatically changed their beliefs about the importance of teaching about scientific models because “it’s what scientists do.” On a more positive note, we were encouraged by evidence that the prospective science teachers’ understandings about scientific models and their intentions to teach using models (instead of about models) changed. These prospective teachers appeared more inclined after the modeling experience to envision engaging their own students actively in modeling, as opposed to merely using models for the purpose of enhancing explanations they provided. This represents a conceptual shift in their views about scientific models as mere representations to actual tools for learning even if they are not aware of how scientists use those tools.

The positive findings of this study include that with the use of a dynamic modeling software such as Model-It, it is possible to engage prospective science teachers in a modeling experience that has potential for expanding their understanding of the role of models and modeling. The modeling experience in this study raised the awareness of this group of prospective science teachers. Similar experiences may provide positive results in other settings. There is evidence to suggest that the context of a science teaching methods course may be an inhibiting factor. The prospective science teachers appeared more concerned with issues of classroom management and time and technological considerations involved in school classrooms, rather than focusing on the importance of modeling in the conduct of scientific inquiry. For this reason, we suggest exploring the use of modeling experiences in other contexts. In particular, it would be important for prospective science teachers to engage in modeling experiences during their undergraduate science content coursework.
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**Note**

This material is based upon work supported by the National Science Foundation under NSF REC 9980055. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

**Acknowledgements**

This article builds upon the work of the Highly Interactive Computing in Education Group (www.hi-ce.org) at the University of Michigan. The authors would like to thank Eric Fretz, Joseph Krajcik, and Elliot Soloway for their support in using *Model-It* and in the development of data collection protocols.

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