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Scientific Modeling for Inquiring Teachers Network (SMIT'N): The Influence on Elementary Teachers' Views of Nature of Science, Inquiry, and Modeling

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Abstract This paper summarizes the findings from a K-6 professional development program that emphasized scientific inquiry and nature of science within the theme of scientific modeling. During the 2-week summer workshop and follow up school year workshops, the instruction modeled a 5-E learning cycle approach. Pre and posttesting measured teachers' views of nature of science, inquiry, and scientific modeling. Teachers improved their views of nature of science (NOS) and inquiry by including scientific modeling in their definitions of how scientists work, the empirical nature of science, and the role of observations and inferences in science. Their definitions of science expanded from a knowledge-based orientation to a process-based orientation. Teachers added the use of mathematical formulas to their views of scientific modeling. Using scientific modeling as the central theme was effective in providing positive influence on teachers' views of inquiry and NOS.

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Introduction

Science education reforms call for teachers to portray science as it is conducted by real scientists (Roth 1995; National Resource Council 1996). Science should be taught using inquiry, emphasizing process skills including scientific modeling, and nature of science (NOS) to improve scientific literacy (Driver et al. 1996). Research shows that though elementary teachers do not have appropriate views of NOS (Akerson and Hanuscin 2005; Akerson et al. 2003, 2006; Bentley 2003), professional development can improve teachers' NOS views and teaching practice (Akerson and Hanuscin 2007; Akerson et al. 2007).

Before an elementary teacher can implement inquiry-based lessons, he/she must experience inquiry-based instruction. The learning cycle (Karplus and Thier 1967; Lawson et al. 1989) is an instructional framework to support inquiry teaching. The three-part learning cycle has since been successfully expanded to a 5-E model (Bybee 1997), as a means to capitalize on student engagement, elicit prior knowledge, and to emphasize formative and summative assessment. We used the 5-E model.

Preparing elementary teachers to use inquiry methods is difficult because many have not experienced this type of instruction (Kielborn and Gilmer 1999), possibly because of confusion about the meaning of inquiry, inadequate preparation in inquiry methodology, and viewing inquiry instruction as difficult (Welch et al. 1981). Knowing science as inquiry is related to understanding NOS. NOS refers to the epistemology of science, science as a way of knowing, or the values and beliefs inherent to the development of scientific knowledge (Lederman 1992). Important aspects of NOS are advanced in *Science for All Americans* (AAAS 1990). These aspects include that scientific knowledge is tentative but robust, no single scientific method exists, creativity and imagination influence the development of scientific knowledge, there is a distinction between observations and inferences, there is a distinction between theory and law, and theory-ladenness (subjectivity) and socio-cultural contexts affect scientific knowledge.

Scientific modeling is a higher-order process skill that incorporates the following fundamental process skills used in scientific inquiry and inherent to NOS: observing, questioning, hypothesizing, predicting, collecting, analyzing data, and formulating conclusions. We used the following definition of scientific modeling for our program: A model is a simple system that reveals properties of a more complex system that you wish to understand better. More than one model can be used to study the same complex system, each model shedding light on some different aspect but each model has limits on type of information. The scientific model is a set of ideas that describe the natural process (Cartier et al. 2001). The use of models is crucial to scientific inquiry. Professional development about models should allow teachers to work in teams to design lessons focusing on models, implement those lessons in classrooms, and revise those lessons based on the experiences of the teachers (Van Driel and Verloop 2002). The Scientific Modeling for Inquiring Teachers' Network (SMIT'N) prepared teachers to help students develop models, formulate explanations and evaluate data as described in the *National Science Education Standards* (NRC 1996). Teachers engaged mentally and physically to develop a deeper understanding of NOS (Hitt and Townsend 2004).

SMIT'N was designed to serve K-6 teachers in professional development using summer institutes, school year workshops, and classroom support. The program was in collaboration with the local school district, and the university science education and biology departments. Our research determines its effectiveness in improving teachers' views of: (a) scientific inquiry, (b) nature of science (NOS), and (c) scientific modeling.

The Participants

SMIT'N served 10 practicing elementary teachers. This paper highlights four teachers: Karen, Vicki, Denise, and John (pseudonyms) who were selected because they were present for the entire program and had completed all of the assessment information. None had participated in any type of science professional development in the past two years. Additionally, Karen and John represented the extreme range of experience, Karen with 24 years and John with 3 years of teaching experience.

Karen was teaching the 6th grade and in her 24th year of teaching. Her high school science courses included earth science and basic and advanced courses in biology. She took geology, biology, and astronomy as an undergraduate. Karen took graduate level courses in geology and biology. Karen was teaching an integrated class with students ranging from identified gifted and talented to students with individual education plans.

Denise taught in 6th grade class of gifted and talented students. She taught elementary school for 9 years and had 6 years of experience teaching at the postsecondary level. Her high school science courses included physics, chemistry, and basic and honors biology. Denise's college science courses included two semesters of biology and a semester of botany. Denise taught science frequently and even reserved the elementary science lab for 2–4 h time blocks to do intensive labs with her students. Denise and Karen worked together on their unit plans to integrate state standards for social studies/geography (biomes) and science (ecosystems).

Vicki has taught 1st grade for 14 years. Her science classes in high school were chemistry and basic and advanced biology. Vicki's college science courses included physics, astronomy, and environmental studies. Vicki created a unit plan on plants and life cycles. She had never used scientific inquiry. She used the opportunity of developing the unit plan to integrate the major topics from the summer workshop. Karen, Vicki, and Denise all taught in a unique elementary school with a diverse student population. Over 34 languages are represented in their elementary school.

John has taught for 3 years, but this was his first year teaching 3rd grade. He taught at a school labeled a "school in crisis" on a less affluent side of town and was concerned about teaching science at a school that failed to make adequate yearly progress. John's science background included high school physical science, two biology courses, chemistry, and physics. During college John completed one semester of chemistry and elementary science methods and two semesters of biology.

Intervention

The summer intervention included a 2 week workshop that focused on science inquiry including process skills, the learning cycle, and nature of science. All topics were included under the umbrella term “scientific modeling” as a tool used in inquiry teaching and learning in science. The sessions were led by a university science educator and doctoral students in science education and biology. Classes were conducted using the 5-E learning cycle to familiarize the participants with this teaching method. Appendix 1 describes the structure and specific daily activities for the summer workshop.

As a culminating event of the 2-week summer workshop, the participants constructed and presented to their peers a life science unit they would teach in the subsequent school year that included inquiry, NOS, and scientific modeling. The main purpose of the unit plan was to synthesize ideas regarding life science content, scientific inquiry, NOS, and scientific modeling into one cohesive unit to serve as a teaching example for other science units they would teach during the school year.

Two school year follow-ups and classroom support from a SMIT’N science education outreach coordinator and two biology graduate students who served as life science specialists enabled us to provide classroom support to the teacher and explore impacts on teacher practice and knowledge. At the first school year workshop teachers explored pill bugs and their habitats. Consistent with the 5-E learning cycle, we began the lesson by reading a story about the life of a pill bug (a popular aspect of the summer workshop was the starting of the day with a relevant children’s book) and a short discussion regarding what the teachers already knew about pill bugs as the *Engage* phase. The teachers made observations and inferences about pill bugs, performed a short guided inquiry about pill bugs’ preferences for light or dark conditions, explored school grounds and nearby woods to find pill bugs, observe habitats and behavior, record findings, and communicated the information with their fellow teachers as the *Explore* phase. When the teachers reconvened for the *Explain* phase, one of the life science consultants modeled how to allow the explanation to be grounded in the students’ observations and inferences. She elaborated on peculiar aspects of *Armidillidium*. Teachers used information gathered from their explorations and explanations to construct habitats suitable for the pillbugs as the *Elaborate* phase. The lesson ended with a discussion about which science process skills were used in the activity as identified in (Ostlund and Mercier 1999), which aspects of NOS could be identified in their exploration (Lederman and Lederman 2004), and four questions to raise with students when using student-constructed models: (1) How is the model like the real thing; (2) How is the model different from the real thing; (3) What misconception could this model give about the real thing; and (4) How could the model be improved? (Eichinger 2005). The teachers then designed posters to help students reflect on NOS, inquiry, and modeling.

The second school year workshop used the theme of “Soil and Critter Interactions.” Teachers were divided into two groups, with half of the participants investigating "terrestrial leaf litter critters" while the other half made observations of "aquatic leaf litter critters" using simple investigation equipment. The *Explain* stage of the activity was led by the two life science specialists using the teachers' observations, inferences, and explorations as a foundation for their discussions of the complexities of life in soil. The lesson was extended with further investigations regarding soil and its relationship with the ecosystem. Part of the second workshop involved a guest speaker leading an interactive discussion regarding his experience with an outside observer in his classroom, how it helped him see what he could not while he was teaching, and how it helped him improve his teaching. He shared this information as part of his own experience in professional development, which we hoped would encourage teachers to invite us into their classrooms more often so we could provide better support.

The outreach requested by the teachers was varied for the school year. The teachers contacted the coordinator when they needed help with a difficult lesson or needed material support. John contacted the outreach coordinator to help adapt a lesson about sound from his curriculum. The coordinator offered suggestions for making the lesson more in line with the 5E learning cycle format and provided materials for a lesson extension. Karen contacted the outreach coordinator for materials to support a lesson. Denise contacted the outreach coordinator to give material and instructional support in teaching a physical science unit about force and motion using model roller coasters. This was an intensive 2-day lesson that required 4 h of instruction. The coordinator supported her in arranging the lesson in a learning cycle format that emphasized the use of models and progressed into a math/science extension that capitalized on her gifted and talented students' ability to use algebra for velocity calculations. Vicki did not contact the coordinator for classroom support though offers of support were extended through e-mail.

Methods

The study used a combination of methods to track the effectiveness of the professional development program on teachers' views of inquiry, NOS, and scientific modeling. Qualitative data collection methods used to determine the effectiveness of the program included teacher discussions, one-on-one interviews, presentations, lessons, unit plans, reflections, correspondence, and observations of teaching during the school year.

Data Collection

Participants' conceptions of NOS and inquiry were assessed before and after the 2-week summer workshop and 3 months after the first school year workshop using the Views of Nature of Science Questionnaire-Form VNOS-D2 (Views of Nature of Science Elementary School Version 2) instrument (Lederman and Khishfe 2002) and the VOSI-E (Views of Scientific Inquiry-Elementary School Version) instrument (Lederman and Ko 2004). The assessment used the written surveys followed by interviews to allow teachers to elaborate on their responses and us to validate our interpretation of teachers' written responses. We interviewed teachers in January using the VNOS-D2 and VOSI-E as interview protocols without having them fill out the surveys.

To assess change in views of scientific modeling, an adapted version of Van Driel and Verloop's (1999) Scientific Modeling Survey was used. The survey was originally written to be used to study pedagogical content knowledge regarding the particulate nature of matter. The survey was written in another language and was roughly translated into English. We modified the survey for a broader use. Words with ambiguous meanings such as "phenomena" were replaced with terms such as "system" to remove the technical terminology. The 20-question survey was given pre and postsummer workshop, but was changed to an open-ended interview protocol version in the January follow-up to elicit richer explanations of teachers' views of modeling. The survey was adapted by identifying categories from the original and forming these categories into questions so teachers could elaborate on their responses.

Videotapes were made of daily content and pedagogy sessions during all workshops. They were used to ensure that explicit reflective NOS instruction took place (Akerson et al. 2000), that scientific modeling was emphasized, and that teachers were engaged in inquiries that allowed them to reflect on the 5-E learning cycle. They were also used to determine how teachers reflected on their intended use of inquiry, NOS, and scientific modeling. Teachers' unit plans were collected to track their ability to incorporate scientific modeling, NOS, or inquiry into their curricula. Classroom visits and interviews determined whether these plans were implemented. Data collection also consisted of follow-up interviews, summer and school year workshop discussions and reflections, general classroom visits, face-to-face interviews, and e-mail correspondence.

Data Analysis

Data analysis focused on comparing pre and postinstruments from the summer workshop, school year workshops, data collected 3 months after the first school year workshop, and data collected in classroom visits during the school year. Two researchers independently analyzed interview transcripts and questionnaires for each data source. Preinstruction interview transcripts and corresponding VNOS-D2 and VOSI-E questionnaires were used to generate profiles of each participant's NOS and inquiry views, prior to and after the summer workshop, and 3 months after the first school year workshop. The profiles were compared to ensure validity. The same process was followed for the postinstruction interviews and questionnaires. The generated summaries for all participants were searched for patterns or categories. Discrepancies in coding led to researchers' discussions which resolved any conflicts in interpretations. The categories of participants' understandings of NOS and inquiry were checked against confirmatory or contradictory evidence in the data and modified accordingly. Several rounds of coding, confirmation, and modification were conducted to reduce and organize the data.

We compared the pre and postteacher responses to the modeling survey to determine any change in views. We noted areas of greatest and least growth to determine areas for future workshop foci. In addition, teacher responses to the follow-up interviews using the modeling survey questions were used to assess change in views at the conclusion of the school year workshops and to elaborate on their views holistically.

To determine the effectiveness of the structure of SMIT'N on teachers' views of NOS, inquiry, and scientific modeling, the researchers reviewed videotapes of workshop sessions, teacher presentations, unit plans, and classroom instruction to track patterns that indicated whether and how teachers were considering NOS elements, scientific inquiry, process skills, and modeling in their instruction. These data sources were coded by noting whether inquiry, NOS, or use of scientific modeling were present, and were tracked over the full year to determine whether there was change in the emphasis on NOS, inquiry, or scientific modeling. Items such as written reflections from e-mails and follow-up school year workshops, video recordings of summer and school year group reflections, summer and school year teacher interviews, unit plans, and summer presentations were collected and used to observe beliefs or use regarding the major themes of SMIT'N. Content analysis (Krippendorff 2004; Neuendorf 2002) on predetermined categories (Merriam 1998) that were themes consistent with the summer and school year professional development: inquiry, nature of science, and modeling was used on the documents. Documents from the summer and follow-up workshops such as interviews, written reflections, and observations were analyzed and identified as being consistent with themes from the interventions among and across themes for validity.

Results

We share results regarding teachers' views of scientific inquiry, nature of science, and scientific modeling. We provide representative quotes to illustrate teacher views.

Teachers' Initial Views of Scientific Inquiry

When asked what kinds of work scientists do, prior to instruction three teachers mentioned processes such as: observing, classifying, experimenting, analyzing, interpreting the world, and looking for solutions to problems. Karen mentioned that a variety of methods were used while John and Denise listed the steps of the scientific method.

The teachers reacted to a hypothetical observational study regarding bird beak shapes and the food the birds eat (Lederman and Ko 2004), sharing their views of whether this investigation was scientific or an experiment. Karen and Vicki thought the work was scientific. Karen explained that scientists use a variety of methods, materials, and sources when doing their work. Denise was uncertain, and thought the scientist had begun to think about a relationship, but had not finished, and was therefore not being scientific. John did not think the work was scientific because not all the steps of the scientific method were used. John, Karen, and Vicki believed the study was not an experiment because the investigator did not have controls and variables. Karen thought the study was an experiment because the investigator made observations and drew conclusions.

Changes in Inquiry Views after the Summer Workshop

After the summer workshop, the teachers expanded their ideas about the work that a scientist does. Three teachers included modeling along with communicating results and measuring and collecting data in their views. Denise's notion of the scientific method vanished, but John's did not. He meshed inquiry with the use of the scientific method, stating "scientists work through the scientific process of inquiry when using the scientific method and incorporate steps like observation, hypothesis, prediction, inference, etc."

When interviewed at the end of the summer workshop, three teachers thought the work was scientific with conclusions being based on observations. John disagreed, stating that no data were collected so it was not scientific. Three teachers thought the work was not an experiment, with no controls or variables. This was the only time that John did not mention the scientific method. Karen retained her view that a study was an experiment.

Changes in Inquiry Views after the School Year Workshop

When the teachers described the work of a scientist, they retained many of their new ideas. All teachers mentioned using process skills, with two mentioning modeling and one mentioning communicating with other scientists as part of inquiry. Three thought scientists observe and infer based on data, but John clung to the idea of scientists following the scientific method stating, "scientists use the scientific method and that tends to be a generally known thing around the world."

Teachers shared their views about the observational bird beak/food study. Karen retained her views that the work was scientific but realized it was not experimental. Karen thought "it may not be the experiment she set up, but the scientist looked at different things, made a hypothesis, and then drew conclusions." Vicki thought it was scientific because the scientist was "inferring on her observations and research and affirming and expanding her views throughout the study." Denise retained her new view, stating "an observational study was scientific, yet there are not enough details provided to be certain and the work was not an experiment." John reverted to his notion that it was not scientific because parts of the scientific method were not used, although he agreed it was not an experiment, stating "she didn't use the scientific method. She is just observing."

The teachers improved their views of how scientists do their work. They stated that scientists make observations and inferences based on the evidence and they use models and communication in their work. John still viewed science operating in a step by step fashion and could not distinguish an observational study from an experiment.

Many of the lessons in the teachers' units were inquiry. Vicki's plant unit was inquiry-based and required her students to conduct guided inquiries. The other teachers' units were inquiry-based or written in the 5-E lesson format. Karen and

Denise planned an inquiry using lentils and dandelions to show the effects of overpopulation. John used inquiry for an *Extend* portion of his lesson as he asked his students to explore body movements when they taped their hands still to experience immobile joints.

Teachers' Initial Views of NOS

Prior to participating, the teachers held many NOS misconceptions. All four defined science as a body of knowledge, with two stating it was gained through the scientific method. They believed scientific knowledge was sure or changed only with new information, indicating they held inadequate views of the tentative aspect of NOS.

The teachers held inadequate views of the sociocultural influences on data interpretation. Vicki and Karen mentioned the impact of one's personal experiences or cultural influences, but Denise and John did not. All thought science was creative but was limited to forming a hypothesis or designing an experiment. Denise held a better view of scientific creativity stating "they can connect facts to make good guesses," and Karen suggested that creativity was used in generating solutions and interpreting findings.

Change in NOS Views after the Summer Workshop

After the summer workshop teachers began to think of science as a way of investigating, an improvement over their views of science as a book of knowledge. The idea that scientists observe and form inferences based on evidence was another view held postworkshop. All but one improved in their notions that a scientist's background affects data interpretation (subjectivity) and scientists may revise their interpretations of data (tentativeness). Teachers improved their views of how scientists use creativity by recognizing scientists use creativity to "construct conclusions," "figure things out," and "explain things that cannot be easily seen."

John had trouble incorporating NOS into his vision of science. He had lingering misconceptions dealing with the tentative, subjective, and creative aspects of NOS. He incorporated terms he heard through the workshop into his explanations but was unable to do so in a way that indicated an appropriate understanding, such as "subjective reality causes the scientists to think differently." John acknowledged that science changes as the "accepted body of knowledge changes." He attributed this change in knowledge to scientists' subjective views. He believed that imagination and creativity are used when things are less known; the nature of the data determines if scientists agree or disagree.

Karen improved the most in her NOS views and mentioned one of the workshop activities when discussing what shaped her views. It was a cartoon of a living dinosaur as compared to a dinosaur reconstructed by the museum scientists. It helped her realize that scientists can never be sure about how they interpret data and that creativity is used in this process. When probed further, Karen shared that these NOS terms were new for her but easy to incorporate; she was active in curriculum and grant writing in her school and for her, the workshop scaffolded vocabulary terms to many of her existing ideas.

Changes in NOS Views at the First School Year Workshop

Some of the improvements in NOS views after the summer workshop were lost as the teachers went back to the classroom. For example, they began thinking of scientific creativity as limited to the planning or hypothesizing of an investigation. Only Denise retained the notion that scientists use their imagination to construct something they cannot see. Teachers made efforts to incorporate NOS in their classrooms, but two talked about "scientists changing their subjectivity," indicating a misconception of subjectivity.

Karen's conceptions were mixed as she integrated NOS aspects with her own views. Karen mentioned the influence of personal and cultural backgrounds on data interpretation prior to the workshop and now realized that these influence scientific inferences. At the first school year workshop, she still had a good view of the social and cultural influence, but she admitted that she forgot what subjectivity is:

> Scientists think differently because of different social and cultural contexts. It may be that they are not willing to look at what other scientists have done and they may just come up with their own theory. They have different levels of creativity and different observation skills…and different interpretations based on what they are willing to accept or not accept. I kind of forget what subjectivity is.

However, two main improvements in NOS views remained. The teachers saw science as a process, more of the "hows and whys" instead of a body of knowledge. An understanding of the distinction between observation and inference was also retained, as is illustrated by Vicki's statement, "they are inferring based on the information they get."

John was the only teacher who improved his NOS views after the first school year workshop. Before and after the summer workshop, John viewed creativity being used only in the hypothesis and predicting stages of an investigation. After the first school year workshop he realized that scientists use creativity throughout an investigation and noted that when dealing with inconsistencies and making conclusions they also use creativity.

Karen and Denise included NOS objectives as part of the unit they developed for the summer workshop. They mentioned that the "overall unit was sort of our NOS study" and shared that throughout this unit:

> The students are going to continually explore about scientists and communicating, and scientists working in groups and alone, and that sort of thing. And bring in personal experiences to connect to their new experiences. We can expect to get some differences of opinions on those. Then we can talk about changing our minds and tentativeness and that sort of thing. We look at using own imaginations to construct understandings of some abstract ideas that we would expect sixth graders to know.

Despite the NOS objectives included in the unit and intention to help students gain NOS understandings, the lesson plans included no NOS instruction or assessments. The teachers revised normal activities without integrating explicit NOS instruction.

When John was asked about how he incorporated NOS, he responded, “I think the usual that most people have mentioned…a lot of tentativeness, subjectivity, observing/inferring, a lot of data collecting.” John included no objectives for NOS, nor did he explicitly teach NOS in his classroom.

NOS Connections to Modeling

The NOS aspects that the teachers retained beyond the summer workshop (the distinction between observation and inference and science as a process rather than a body of knowledge) were a result of the connections teachers made between process skills, modeling, and NOS. By explicitly teaching the process skills, the teachers began to use them to form their definitions of science. But when asked directly about NOS and modeling connections, none of the focus teachers could recall the “names” of the NOS aspects and needed prompting or a printed list of the targeted NOS aspects to respond.

After being reminded of the NOS aspects, Vicki was able to identify NOS aspects in her classroom clay modeling activity. She described how some students based their work with the clay on their previous experiences, such as whether it would get hard or soft again when water was added as an example of subjectivity. She noted that the students made many observations and then made good inferences in their activity.

Karen shared that theory and law were difficult for her students and modeling might help them understand them better, though she did not offer an idea for how to do so. Denise stated that she did not have NOS “in her head yet” and could not make connections for her students. John shared the most connections between NOS and modeling, which actually reflected John’s poorer NOS views. For instance, he saw creativity as the making of the model. He thought scientists make observations and inferences to compare and find differences between two things, like an organism’s footprints against their fingers or bones. He thought theory and law and social and cultural aspects of NOS fit with modeling, but he could not explain how.

Teacher Views of Scientific Modeling

The overarching theme of the summer and follow-up workshops was the concept of scientific modeling. Modeling was used in SMIT’N in many different ways. It was introduced as an integrated process skill, using basic process skills to build an understanding of a concept and then to represent attributes of that concept. Modeling was connected to various stages of the 5-E learning cycle, whether used as a student-constructed product for summative assessment, as an extension, or an explanation as a means of formative assessment. Modeling was used as a product of inquiry as a means for communicating findings. It was used with NOS to discuss specific aspects of a model (models are based on empirical evidence, models are tentative because they may change in light of new evidence, modeling is a subjective process because of the learner’s prior knowledge and experiences, etc.).

Types of models, attributes of models, and analyzing models were also addressed at various times during summer and follow-up workshops.

To understand how the teachers' perceptions of models changed over time, we asked open-ended questions so teachers could describe their conceptions of scientific models and their views of how scientists use models. These questions were asked on the first day of the summer workshop, on the last day of the workshop, and in a follow-up interview about 6 months after the workshop. Table 1 shows the teachers' responses changed over time.

Table 1 shows a slight improvement in teachers' definitions for models at the end of the summer workshop, but in the January interview, the teachers have a weaker description of models, despite the fact that they had been teaching science using models. In the January follow-up interview John, Vicki, and Denise related their views of a model as being "something that represents something else." This definition may be explained by the emphasis in the January workshop on reflecting on the relationship of the model and its target (Eichinger 2005). Karen gave elaborate responses, stating that models represent systems and relationships, and can communicate and understand nature. In the January interview both Karen and Denise thought models communicate ideas for understandings, perhaps because they worked together designing and implementing unit plans that included modeling activities as a form of alternative assessment.

When asked about the purpose of models, three of the teachers moved toward ideas of models being the result of an investigation, perhaps because the summer and follow-up workshops heavily emphasized that modeling was an integrated process skill that culminated in a way to communicate one's findings (See Table 2). Three also responded with answers relating to the use of models as a way of *constructing* something in the classroom, which show their views relate more to student-construction rather than production of scientists. John stated:

> So I guess, like I said before, to be able to make it easier to study certain things. For instance, in my class we created mini-habitats of isopods and we could say that is the model of their environment, their habitats. The purpose of

Table 1 Teacher description of a scientific model

	Preworkshop (written)	Postworkshop (written)	January interview
Karen	Shows how all the parts of a system work together	Illustrates an event or thing. Explains a relationship. To help us understand our universe	To communicate and understand
John	A way to organize information on a specific scientific topic	A representation of something studied on some branch of science	To represent something
Vicki	A realistic representation based on current knowledge	A partial representation of something real or how it works	Represents a real situation
Denise	Compares things or shows relationships	2D or 3D; describes a system or something too large, small or complex to be seen	A version of something; to explain

Table 2 Teacher description of the purpose(s) of a model

	Preworkshop (written)	Postworkshop (written)	January interview
Karen	Scientists use models to study/observe and explain how things work, relate, produce	To study how things work, how parts interact, how it interacts with other systems.	For theories and teaching
John	To organize what is learned and to share: teach what is known	To get (learn) a better understanding or give (teach) a clearer understanding of a concept.	To visualize something—to study it—to make it easier to study it
Vicki	To show what they know and to study	To help them understand what they observe and infer. Models can change based on future evidence/discussion.	To investigate/explain—to look for change, etc
Denise	Compares/shows relationships between things that cannot necessarily be observed	To reflect or understand; to communicate with other scientists	To figure things out—to think about things and to revisit and moves things around (change)

that, and that I call it an effective model, is that it's easy for the kids to be able to see certain aspects of an isopod's life and living as opposed to having to go outside everyday to do that.

Vicki stated that models give a way to "possibly manipulate things, to see how things work, to make observations, and to see how things interact with each other." She gave examples that models can be used to represent, such as "ecosystems."

Karen was the only teacher at this point to reflect on the use of models by both scientists and by teachers and students when discussing the purposes of models:

I think it can prove theories, as I said for scientists, and then as far as educators, it can help them understand, I mean that's the way I can understand something that I'm a specialist in that area and take it further, it helps children understand.

Models in the Classroom

Teachers used models in their classrooms in a variety of ways. Vicki had students make observations and then describe that models, such as toys, are like the real things in some ways, but different in others. John asked his students to explain how a model of something is different from reality but can be used to learn something about the real thing. Denise and Karen asked their students to use models to demonstrate processes that happen too slowly, too quickly or on too small a scale to observe, are too vast to be changed deliberately, or are potentially dangerous.

Teachers stated they often used scientific models in the classroom, and there were connections in the unit plans that showed practices supporting the state standards regarding models. For example, the third grade standard, "explain how a model of something is different from the real thing but can be used to learn something about the real thing" was apparent in John's unit plan when he had students assemble a model of the human skeleton—first from memory, then with discussion, and finally with an accurate model to guide them. This process was repeated in subsequent lessons.

Models as Assessment

A common theme throughout the unit plans was using scientific modeling as a form of assessment. For example, Vicki made the following statement about using models near the end of her unit on plants and life cycles using *Brassica* plants:

> As far as modeling, we have the bees, and then at the end, one of the assessments is a visual model of a plant and they need to identify what all the parts are and it's pretty detailed: bud, seed pod, all of that. And that's mainly the focus of the evaluation for this, it's the record keeping, the drawing, the writing, and they really understand the structure of the plant.

She used a two-dimensional picture as a model in which the students would relate their knowledge of plants and their structures (the target).

Denise and Karen used modeling for evaluation by having students construct microcosms of an ecosystem. Their plan for using modeling as an assessment is shared through their reflection:

> At the end, the culminating thing will be when they create their own plant or animal based on the biome they studied which tells us whether they understand their own biome and the adaptations necessary for something to live. They will create an animal or plant that can adapt to this biome, write an encyclopedia entry for the creature and make three-dimensional creatures. This will culminate everything they've learned with one assessment: will it be able to fill a niche or compete in that environment?

Karen further elaborated in a follow-up interview her idea of modeling as a form of alternative assessment:

> A model can be used to help children understand, and then it can be used as an evaluation tool for the teacher, when you ask a child to make a model, it can help. You see if they do understand the theory or how something works or whatever, and not necessarily have to know all the scientific terminology.

Karen realized that modeling may be an effective way to assess a student's understanding of big ideas rather than rote recall of concepts and vocabulary.

Models as Instructional Tools

We found that teachers mentioned through reflections, presentations, unit plans, discussions, interviews, and classroom observations that they were using models as a way of teaching, usually implementing models into the learning cycle. Karen and Denise used models as part of an elaboration phase of the learning cycle in their unit on invention in addition to their SMIT'N-prepared lesson plan. John used models in many ways including the construction of environments such as pill bug and ant habitats. Denise used models for various topics as she described:

> This year…we've done models of how diseases spread. We've done biomes. We've done everything from drawing to construction of things. We are doing simple machine models with the Rube-Goldberg setups. We're going to be doing roller coasters for Newton's laws in physics. I'll be doing rockets, I hope, later on. So obviously we're not shooting real ones! Oh yeah, and we're modeling ocean currents. There are a lot with ocean currents; we've done models with waves and ocean currents with watering tubs and modeling tubs and modeling currents…heat…cold.

Based on interviews, reflections, and classroom visits, we see teachers have used scientific modeling in their science instruction. Models were used for students to construct ideas, but fewer models were built as a result of true student inquiries.

Discussion

We found that teachers gained in their understanding and practices of inquiry, NOS, and scientific modeling. We discuss these gains in the following sections, and describe implications for professional development programs.

Scientific Inquiry

From our research we found that the teachers readily began to use the learning cycle as a structure for leading their students through inquiries. They used the 5-E format as a structure for designing their own lessons and inquiries, and modified their existing lessons and extended the 5-Es over several lessons. In reflections about how their science teaching has changed, they discussed how the concept of "exploration before explanation" was beneficial for students. Allowing students to explore ideas prior to discussion of science content enabled them to better interpret explanations.

We believe that the learning cycle was so readily adopted by the teachers because we structured all our inquiries throughout the summer and school year workshops using the 5-E format, as well as asked teachers to reflect on our inquiry lessons to "pull apart" different stages of the 5-E learning cycle so they could identify these stages for their own instruction. We required them to write their unit in the 5-E learning cycle format. Thus, they had experienced learning science through this format, as well as designing lessons in this format, which served as a model for how they would teach the following school year.

Nature of Science

We found that the teachers improved in their views of NOS after the first summer workshop, and those new views were sustained for some NOS aspects. The aspects that were retained were the distinction between observation and inference, and science as a process versus a step-by-step method. These NOS aspects are the ones most easily connected to process skills and scientific modeling, making them easier to emphasize throughout workshops as other goals such as modeling were taught. We noticed by the first school year workshop that although the teachers did not have the "correct" terminology for the NOS aspects, many could describe the ideas, as Kim could describe her views of scientific subjectivity although she did not recall the specific "workshop definition." It is arguably more important to internalize concepts rather than memorize the terms.

Teaching the teachers about NOS embedded in the focus of scientific modeling did not work as well for John. John was the only teacher participating in SMIT'N at his school. The other three teachers were all at the same school, enabling them to share ideas and work together. Denise and Karen also worked together on their planning and teaching, requiring them to share ideas. John was a relatively new teacher in comparison (though number of years of teaching experience does not seem to be related to ability to teach NOS—see Akerson et al. 2006; Akerson and Hanuscin 2007), working at an identified "school in crisis," and still trying to teach science in the midst of an emphasis on reading and mathematics. He used the outreach coordinator for support, so it was obvious he wanted to teach science in a way in line with SMIT'N, but that did not help to improve his views of NOS.

Scientific Modeling

Using scientific modeling as an overarching theme proved satisfactory for enabling SMIT'N to emphasize NOS and scientific inquiry. Teachers were able to grasp the concepts of scientists using scientific modeling to represent ideas. Scientific modeling proved useful in illustrating the distinction between observation and inference as teachers were asked to make observations and use their inferences to make their own models. Additionally, scientific modeling was used to show how scientists create (illustrating the creative NOS) models to make explanations from data (empirical NOS), and these models are robust because they are created from data, but also tentative (tentative NOS) because scientists could change the models depending on a re-interpretation of existing data or collection of new data. We found that we did well in emphasizing the distinction between observation and inference with our instruction on modeling, but recommend making stronger connections to the other NOS target elements.

Teachers used scientific modeling in their science instruction. They had their students build models from investigations and interpret those models. They used the same debriefing questions with their students that we used in our workshops. Students anticipated these questions after building models and articulated their thoughts.

Teachers described using models at various stages of inquiries in terms of the learning cycle. Teachers used models mostly at the *Elaboration* stage of the learning cycle, finding it a good place to ask students to apply their scientific knowledge. Teachers found scientific modeling to be useful in authentically assessing their students' understandings—they stated that it gave them a better picture of what students understood about the science than using more traditional assessments.

Implications and Recommendations for Professional Development

We found that the use of scientific modeling as an overarching theme for professional development that focused on NOS and inquiry was effective in enabling us to connect the goals to one theme, but it seemed most effective for inquiry because teachers attained and retained understandings and teaching strategies for NOS to a lesser degree. Part of this difficulty could be emphasizing the NOS aspects as well as modeling and inquiry in one workshop. However, also problematic was that teachers had not before heard the term “nature of science,” yet had already heard of modeling and scientific inquiry. Therefore they had reconceptualized their views of inquiry and modeling as a result of participating in SMIT’N, while they had no prior views of NOS to reconceptualize, and so had to develop an awareness of NOS. We recommend connecting the NOS aspects through inquiry via scientific modeling by describing the distinction between observation and inferences as teachers were making their own observations and inference while building models. Holding explicit discussions of how scientific models are scientifically creative (illustrating the creative NOS) that come from data (empirical NOS) and can change via reinterpretation of that data or collection of new data (tentative NOS) should better help teachers conceptualize the NOS ideas and provide examples for how to emphasize NOS within the context of scientific modeling. Those connections need to be made by the workshop facilitators, so teachers can more fully conceptualize the new ideas and retain them (Akerson et al. 2006).

Other features we would retain for professional development are to provide the outreach coordinator and biology specialists for the teachers. The outreach coordinator was a contact person for the teachers to obtain extra support in terms of providing materials, classroom instruction, and feedback. The biology specialists provided content support as well as classroom instruction to the elementary students of the teachers. However, we believe the outreach coordinator and biology specialists could have been used more effectively. The teachers were initially reluctant to contact the outreach coordinator and biology specialists. It could be that they were uncomfortable having someone else in their classrooms, or that they were not aware of effective ways to use the offered support. We recommend inviting a person in to talk with teachers about the usefulness of an extra pair of eyes and hands on the classroom earlier—possibly toward the end of the summer workshop. We noticed an increase in use of the outreach coordinator and biology specialists after the professional development speaker came.

Regarding the format of the workshop, we recommend retaining the intensive summer workshop followed by school year workshops. The intensive summer workshops allow teachers to be involved in scientific inquiries that lend themselves to designing scientific models, emphasizing process skills, and NOS elements. The school year workshops allow the professional development team to provide support throughout the year to the teachers. The teachers can discuss issues related to their classroom practice and in trying out new strategies, while the professional development staff can reinforce new understandings and emphasize teaching approaches to better support the teachers in their classrooms. We think it would have been beneficial to have more than two school year workshops—one in the fall and one in the spring were not sufficient in helping us engage the teachers in discussions of their practice, and in allowing us to reinforce new conceptions and teaching approaches. We believe that more school year meetings would aid in the retention of new views and in the implementation of new teaching approaches.

Appendix 1

Structure of summer workshop

Day	Intervention/Class	Class description/Topics
Monday AM	Introduction/Pretest & Modeling (Summer Jobs)	Introduction to mathematical modeling and application to teaching science
Monday PM	Process skills including modeling	"Model an Axolotl" lesson using process skills and culminating in modeling activity (learning cycle format)
Tuesday AM	NOS & Inquiry	Introduce nature of science aspects to teachers
		Help teachers recognize science as inquiry and different types of inquiry, which then allow teachers to emphasize the nature of science aspects
Tuesday PM	Evolution (including the learning cycle)	Introduce the 5-E Learning Cycle model and different levels of inquiry (open, guided, structured, directed)
		Engage teachers as students in "Too many" learning cycle including over-reproduction in fruit flies & dandelions
		Engage teachers as students in "Studying the Past" learning cycle including fossil bone & animal tracks inferences
Wednesday AM	Biodiversity	Engage teachers as students in "Living/Nonliving" learning cycle including NOS discussion of how we know about life
		Engage teachers as students in "Cell Diversity" learning cycle including microscope work with plant & animal cells
		Engage teachers as students in "Flower Pollination Adaptation" learning cycle including flower modeling
Wednesday PM	Interdependence of life	Introduction to biodiversity and how interdependent the components of an ecosystem are. Modeling of basic forest food chains and food webs. Bottle biology eco-columns
Thursday AM	FOSS for K-5 w/ connections for 6th grade	Engage teachers in pedagogical strategies for incorporating NOS and inquiry and into their textbook science series. Focus on integrating other subject into science activities
		Examples of inquiries: mystery boxes, children's literature, cotton ball catapults, sound
Thursday PM	FOSS for K-5 w/ connections for 6th grade	Teachers looked through curriculum to find examples of inquiry based activities and challenged to rewrite cookbook activities into a inquiry format
		Debriefed cotton ball activity with graduate physics instructor to explain concepts used in activity

Appendix continued

Day	Intervention/Class	Class description/Topics
Friday AM	Human Identity / Body	Engage teachers as students in studying cells in an inquiry format emphasizing NOS aspects
		Engage teachers in a learning cycle format to study viruses using an interactive human modeling scenario
		Engaged teachers as students in an interactive human modeling about the digestive system
Friday PM	Unit Planning	Teachers met in grade level groups to select unit topics
Monday AM	Modeling activity (Bigfoot)	Demonstrate a guided inquiry and mathematical modeling.
Monday PM	Group Work	Teachers worked on developing their units
Tuesday AM	Models Misconception s/ Developmental Issues	Describe Piaget's stages, developmental aspects of teaching models, novice & expert views of models, strategies for teaching using models
Tuesday PM	Group Work	Teachers worked on developing their units
Wednesday AM	Group Work	Teachers worked on developing their units
Wednesday PM	Human Activity	Engaged the teachers in an inquiry solving the mystery of the ultra-violet beads and leading to a discussion of related environmental problems. Debriefed NOS aspects into discussion. Introduced aspects of human impact on the environment and overall ecosystem biodiversity, included invasive species of North America
Thursday AM	Assessing Student Outcomes	Introduce strategies for teachers to assess students' views of models, NOS aspects, inquiry, and biology content
		Developed rubrics for student assessment.
Thursday PM	Group Work	Teachers worked on completing their units and in designing their presentations
Friday AM	Endangered/Extinct	Engage teachers as students in "Endangered-Extinct" learning cycle including simulations involving endangered world mammals and locally endangered species
		Engage teachers as students in "Adaptation & Environment" learning cycle including camouflage simulations and cacti modeling
Friday PM	Group Presentations Posttest/Planning	Teachers presented their units to their peers

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