Journal of Science Teacher Education (2007) 18:243–269
DOI: 10.1007/s10972-007-9039-6

Technology, Pedagogy, and Epistemology: Opportunities and Challenges of Using Computer Modeling and Simulation Tools in Elementary Science Methods

Christina V. Schwarz, Jason Meyer, & Ajay Sharma
College of Education, Michigan State University, East Lansing, MI 48824, U.S.A.
e-mail: cschwarz@msu.edu

Published online: 1 February 2007

This study infused computer modeling and simulation tools in a 1-semester undergraduate elementary science methods course to advance preservice teachers' understandings of computer software use in science teaching and to help them learn important aspects of pedagogy and epistemology. Preservice teachers used computer modeling and simulation tools within their own science investigations; discussed general technology issues; and explored, evaluated, and taught their peers about a particular modeling tool. Preservice teachers expanded their vision of the software available and the role that software can play in science teaching, but desired fun, easy-to-use software with scientifically accurate information within a clear, familiar learning task. Such conflict provided a fruitful platform for discussion and for potentially advancing preservice teachers' pedagogical and epistemological understandings.

Introduction

Tomorrow's teachers need to be prepared to use technology in their classrooms (U.S. Department of Education [DOE], 1996; International Society for Technology in Education [ISTE], 2003). Calls for more technology in the classroom (DOE, 1998) and technology standards (ISTE, 2003; International Technology Education Association [ITES], 2000) serve to emphasize this point. Research has shown that technology integration in the classroom has been slow and difficult for a number of reasons (Windschitl & Sahl, 2002; Zhao & Frank, 2003). For example, school computers are often not maintained. Schools frequently lack appropriate building infrastructure, including network connectivity and technological support. There is often insufficient pedagogical support for teachers, as well as professional development and time. Teachers need help learning about good software (as there is a dearth of state-of-the-art software for K-12 schools that remains stable on current platforms) and help determining how to reshape their teaching and classrooms to allow for meaningful and authentic computer use (Sandholtz, Ringstaff, & Dwyer, 1997; Windschitl & Sahl, 2002).

One way of addressing technology integration is by further incorporating strong examples of technology within teacher preparation programs and helping preservice teachers think about how to infuse strong examples of technology in their own future classrooms (DOE, 1998). The hope is that, if new teachers better understand what technology integration looks like and how to accomplish technology integration using strong research-based pedagogies, they will continue to use it in schools once they start teaching. If one takes this goal as a premise, the questions then become: How can preservice teachers learn about technology integration? What might this look like? What might we be able to expect preservice teachers to learn regarding technology use?

This paper reports on a study whose goal was to infuse a particular kind of technology within an elementary methods course. Specifically, we introduced, used, and helped preservice teachers learn about and engage with modeling and simulation software within an elementary science methods course. In conducting our study, we aimed to find out what preservice teachers learned about educational software and how the intervention shaped their views of science pedagogy and their understanding of scientific epistemology. It was our hypothesis that computer modeling and simulation software might play a pivotal role in helping preservice elementary and middle school teachers learn about robust uses of technology in the science classroom within the larger context of helping them advance their understanding of science pedagogy and epistemology (Cullin & Crawford, 2003). The remainder of this paper further explains our motivations and goals, the framework for the project, the nature of the technology integration, our findings, and implications from our findings.

Why Modeling and Simulation Tools?

Computer modeling and simulation software lies at the core of scientific practice and has revolutionized science and engineering (Morgan & Morrison, 1999). Computer modeling and simulation software represents data or phenomena in ways that can help predict and explain those phenomena, often by visually representing abstract components and causal relationships over time. The importance of such software can be seen by observing the central role computational modeling plays in such aspects as forecasting the weather, analyzing atomic and molecular structure, determining the physics of the early universe, and understanding human reasoning. Further, educational versions of such software enable students and teachers to visualize and develop reasoning about abstract scientific concepts and phenomena, access cutting-edge scientific research, engage in authentic practices of science—and do so in interesting ways (Feurzeig, 1994; Feurzeig & Roberts, 1999; Gilbert, 1991; Lehrer & Schauble, 2000; Mellar, Bliss, Boohan, Ogborn, & Tompsett, 1994; Passmore & Stewart, 2002; Raghavan & Glaser, 1995; Schwarz & White, 2005; Spitulnik, Krajcik, & Soloway, 1999; White & Frederiksen, 1998). Studies of such software use in the classroom have shown that, in conjunction with reform-based science instruction, they can foster conceptual change, systems thinking, and subject matter knowledge by helping learners engage in scientific practices, such as visualizing and embodying theories of abstract concepts or ideas into models, gathering information and data from simulations and models, and testing those models.

Nonetheless, while computer simulation and modeling software is vital to science and engineering—and important for producing critical learning outcomes in science education—computer-modeling software designed for educational use is not widely known about or used in K-12 education (Becker, Ravitz, & Wong, 1999; Cullin & Crawford, 2003). In general, teachers have little knowledge of and access to computer modeling and simulation software; often lack the technical knowledge, scientific knowledge, and community support needed for incorporating such software; and usually have little knowledge of the important role that computer modeling or computational modeling plays in science. As teachers are being increasingly asked to use computer technology in substantial ways for which most are unprepared and because scientific modeling and computer modeling software can play a powerful role in learning science and about science, it was our goal to help preservice elementary and middle school teachers learn about and use computer modeling and simulation software for their own science learning and teaching within a one-semester, undergraduate elementary science methods course (Schwarz, Meyer, & Sharma, 2004).

Our hypothesis for this study was that, by carefully integrating into this methods course some computer modeling tools that have been shown to foster student learning, preservice teachers might become more knowledgeable consumers of computer technology and understand some of the issues in using technology for teaching science in the classroom. Specifically, we hoped that the preservice teachers might come to understand some of the powerful uses computer technology can play in teaching and learning science and recognize how to evaluate and integrate some of the strong pedagogical computer software tools into their teaching. Throughout this process, we also hoped that using and thinking about modeling tools would help preservice teachers begin thinking of science and science learning as a process of creating and revising scientific theories or models by generating and evaluating evidence within a scientific community.

We note that, while primarily focusing on enabling elementary preservice teachers to experience and investigate modeling and simulation tools may seem somewhat counterintuitive (as there are more basic forms of software that may be more approachable for beginning teachers learning to use technology), the previously described benefits of such tools are worth exploring to determine the outcome of such an intervention on preservice teachers' understanding and beliefs about technology and science teaching. Further, we do not advocate a teaching approach for which modeling and simulation software are the exclusive form of technology used in the science class; rather, these tools should be strategically combined with a suite of additional tools that can enable data collection, analysis of evidence, and communication.

Theoretical Framework and Goals for Our Study

This work builds and expands on several areas of educational research. For example, we concur with prior work suggesting that scientific modeling can play a central role in enhancing the learning of science (Feurzeig & Roberts, 1999; Mellar et al., 1994) by helping learners externalize ideas and theories into models, evaluate models, revise models, and use models in their own reasoning. The modeling and simulation software used in this study can be classified as theory-building, inquiry tools (Bruce & Levin, 1997).[1] The Bruce & Levin taxonomy includes four categories of educational technology:

1. *Media for inquiry*, including those for (a) theory building (models and simulation toolkits), (b) data access (databases and libraries), (c) data collection (microcomputer-based laboratories), and (d) data analysis (spreadsheets, image processing, and statistical packages);
2. *Media for communication*, including word processing programs, e-mail, and collaborative data environments and teaching media, such as tutoring systems and drill and practice systems (and instructional simulations);
3. *Media for constructing*, such as computer-aided design; and
4. *Media for expression*, such as drawing and paint programs.

We chose to focus on helping preservice teachers learn more about the tools for inquiry (#1) and communication (#2) in science education, with the focus of our attention on media for scientific theory building (#1a), as these are consistent with our pedagogical and epistemological perspectives.

Our pedagogical framework is based on the framework relating to science teaching orientations (knowledge and beliefs about the purposes and goals for teaching science) as proposed by Magnusson, Krajcik, and Borko (1999). Such orientations include didactic, discovery, activity driven, process oriented, conceptual change, problem-based learning, guided inquiry, and others. Research has shown that science-teaching orientations (along with teacher content knowledge and many other factors) probably play a large role in determining how teachers teach science. Our study aimed at helping preservice teachers understand and use a model-based, guided-inquiry orientation in teaching. By model-based, guided inquiry, we mean an approach in which teaching science is seen as a way of engaging learners in understanding and creating scientific models using the tools (e.g., computer models and simulations) and practices (e.g., inquiry) of the scientific community. We note that aside from teaching orientations, others have investigated different aspects of teacher content knowledge and pedagogical content knowledge about scientific modeling (Cullin & Crawford, 2003; Justi & Gilbert, 2002; VanDriel & Verloop, 2002), which indicates that teachers often have a limited view about the role of models and modeling in science; and they rarely engage their students in the process of modeling, perhaps because of a lack of specific instructional strategies to do so.

We also subscribe to the idea that learners' epistemic knowledge, or knowledge about the nature and status of scientific knowledge, is important to address and align with the purposes and practices of science (Carey & Smith, 1993). Epistemic knowledge is an important component of scientific literacy. We build off the

[1] We note that while many taxonomies exist for classifying educational technology (e.g., NETS), the Bruce and Levin (1997) categorization covers a wider range of uses, including cutting-edge uses of educational technologies.

framework proposed by Driver, Leach, Millar, and Scott (1996), suggesting that learners' epistemological reasoning is often phenomenon based or relation based, rather than model based. For learners to be scientific literate with respect to epistemology, we need to enable them to know about and use model-based reasoning, which is characterized by evaluating theories and models with evidence, and to use hypothetico-deductive reasoning, which entails conjecturing and testing hypotheses, models, and theories.

The work presented in this study aims to help preservice teachers understand more about theory-building software tools, while developing a model-based inquiry perspective in understanding both scientific pedagogy and epistemology. By *model-based inquiry perspective*, we mean a perspective in which science and engaging in science is seen as a process of understanding and creating scientific models through revision, reflection, application, and argumentation within the context of inquiry and application. The focus of such an approach is both on the processes of science and on the habits of mind that operate in that community by using the tools and practices of the scientific community.

Nature of the Intervention

To prepare preservice elementary and middle school teachers to use technology in their future science classrooms while learning about scientific pedagogy and epistemology, we designed an intervention in Christina V. Schwarz's (first author's) one-semester elementary science methods class at a large state university in the Midwestern United States in which the 25 preservice teachers used and studied computer modeling and simulation software within their own learning of science and teaching.[2] The intervention included three core components: (a) the use of two computer simulation toolkits within science investigations to see, experience, and reflect on how technology can be incorporated into science teaching; (b) discussions about technology and modeling tools to provide a rationale and framework for technology integration; and (c) investigations of one of five particular modeling and simulation tools in science and incorporation of those tools in science lesson plans to help preservice teachers envision how they might use such tools in their own science teaching. Additionally, we note that this intervention was designed to fit into a methods course with multiple objectives. As such, the technology component was not meant to be the primary focus; rather, it was meant to enhance the main course objectives of helping preservice teachers align their visions of science teaching with reform-based approaches to science education and to develop some preliminary pedagogical tools and techniques to do so.

[2] Students took this methods course in the first semester of their senior year within a 5-year program involving a year-long internship after the senior year. This course is the only science methods course they take before they become credentialed teachers, though many take a one-semester science content course designed for future elementary science teachers.

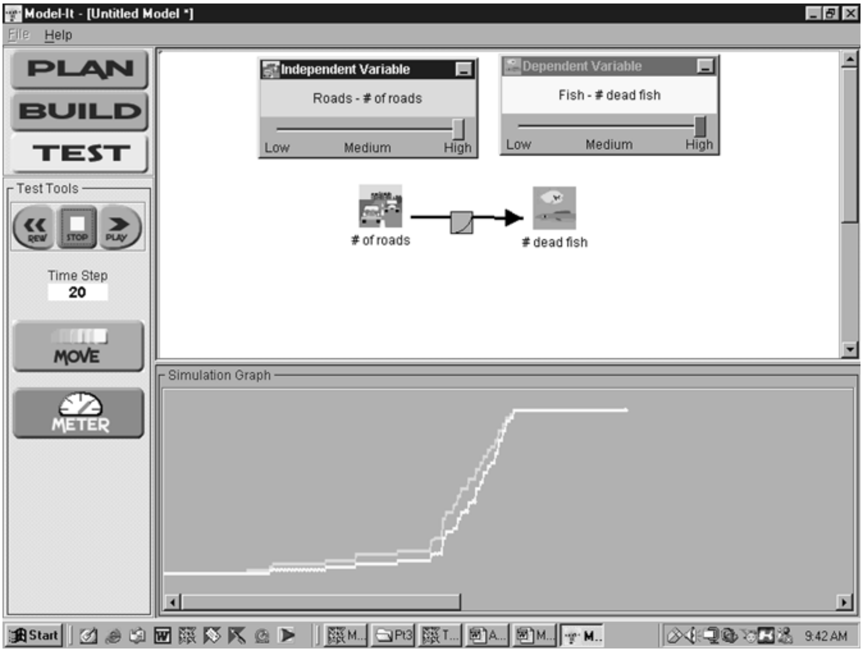

Figure 1. *Screen shot of the software Model-it*™.

Obtaining and Evaluating Software for the Web Site

The project began by searching for examples of computer-modeling software that preservice teachers could use in their own learning and teaching of science that have been shown in research to enhance learning outcomes in science through conceptual change or mental-model development. We selected a variety of commercial and research software that was K-8 appropriate and addressed life, physical, and earth and space science topics.

After obtaining and exploring such tools, we evaluated them and placed these evaluations, as well as information about ways of obtaining the tools, on a Web site (http://ott.educ.msu.edu/2002pt3/). We hoped that, by assembling these tools and their evaluations on a Web site, preservice teachers might be able to use this as a useful resource with important evaluative information. We chose evaluation criteria that were both important for addressing student learning and meaningful to teachers, such as ease of use, quality of the software design, and how state science education standards are addressed. We also provided sample evaluations of those tools on the Web site for students to see how to choose and evaluate the software tools. See Figure 1 for a sample screen shot of the software tool Model-it™. See Figure 2 for a sample screen shot of the software tool ThinkerTools™ (http://thinkertools.soe.berkeley.edu/).

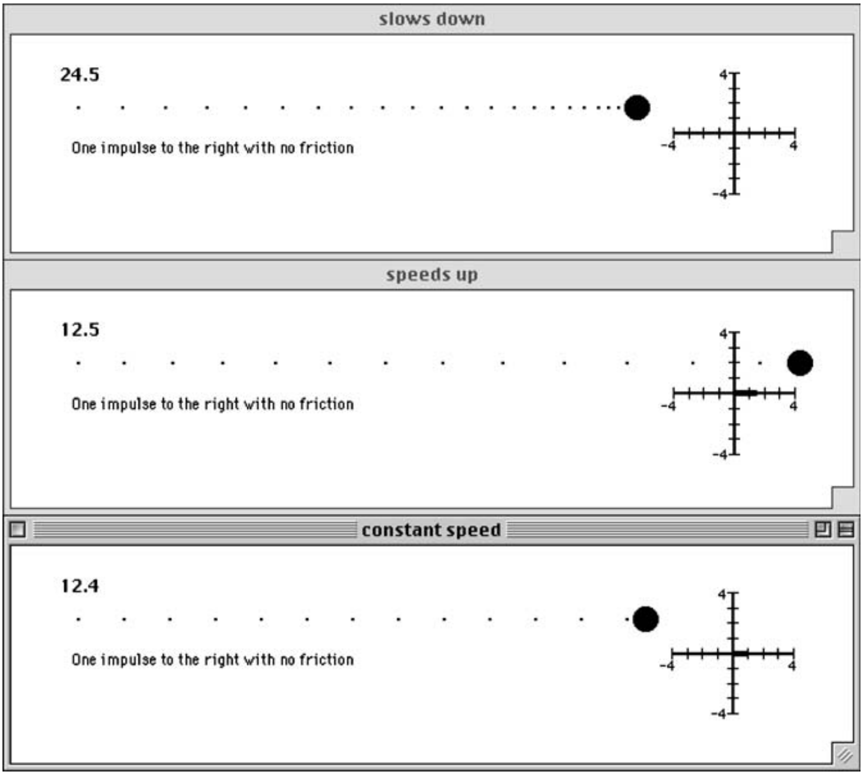

Figure 2. *Screen shot of the software ThinkerTools*™.

Using Software While Learning Science

One of the most important components of this intervention was enabling preservice teachers to learn about and use two simulation tools within their own science explorations during the first 8 weeks of the course. The purpose of this part of the project was to help preservice teachers see the benefits of using technology and to envision what this might look like and how this might be done in science. As such, Schwarz modeled the use of technology in the context of two subject-area investigations on solar motion and light. Specifically, the class used software tools while conducting investigations to understand the apparent motion of the sun across the sky (How and why does the sun's position change in the sky?) and the nature of light (How does light travel? What makes light energy? What causes shadows to occur?).

Within those two investigations, preservice teachers used the simulation software of Starry Night™ (http://www.starrynight.com) and Riverdeep's ZAP!™ (http://www.riverdeep.net). Starry Night is a simulation program of the night sky and allows users to view the sky from any position on Earth—at any time of day and from any time in the past, present, or future. Preservice teachers used the software to collect data on changes in the sun's motion by observing the position of the sun throughout the year at specific locations. The software was particularly useful for helping the preservice teachers see the patterns of solar motion over a short period of time (as one can speed up the simulation to see the motion) and without any observational difficulties (cloudy weather, buildings blocking the view.) Furthermore, the software provided positional tools (East and West markers) for the preservice teachers, which facilitated their location of the sunrise and sunset positions on the horizon. Once preservice teachers used the software, they built physical models (with clay, balls, and toothpicks) to represent solar motion.

In a similar fashion, the light portion of ZAP!™ can be used as a simulation environment for gathering data and solving problems related to lasers. Preservice teachers used the software to investigate the nature of light and shadows (What causes a shadow? Why?) by gathering information about how light interacts with such objects as lenses and mirrors. The software enables users to easily use different kinds of equipment and see the effects of how laser light travels and interacts with different kinds of objects.

Preservice teachers used Starry Night twice during the semester for roughly 45 min and ZAP!™ once for 20–30 min. In doing so, preservice teachers used two examples of inquiry software that enabled them to collect data and more easily visualize the patterns of solar motion and light. Furthermore, we hypothesized that using the software and building physical models would assist preservice teachers with understanding and using models, while helping them engage in model-based reasoning.

Discussing and Debating Educational Technology

During the 9th week of the 15-week semester, preservice teachers read about and discussed the nature and purpose of technology in education. The readings and debate were meant to lay the rationale and framework for later discussion and exploration of the modeling and simulation software. Specifically, they were designed to highlight the potential benefits of technology, the pitfalls of technology (using computers as babysitters or as reinforcers of rote skills), as well as the tensions of using technology in the schools (how many computers should there be in each classroom, upkeep of the technology, which software to purchase or use, and teacher education about the technology).

As a result, preservice teachers read two methods text chapters (Koch, 1996; Martin, Sexton, & Gerlovich, 2001) and wrote journal entries answering four questions related to the text reading:

1. How much (if any) should technology be a focus in the classroom? Why?
2. What qualities or criteria should educational software have to be best used in your classroom?

3. What are some effective uses of technology in the classroom? Ineffective or bad uses?
4. Write about some ways you can incorporate technology into your lesson plans.

The texts included ideas about productive uses of computer tools for teaching science, including inquiry tools for theory-building (microworlds) and making observations and gathering such data as the Web and software simulations, communication tools (e-mail), and expressive tools (word-processing and paint programs). During the class session, we discussed the criteria of software needed for effective uses in the classroom and good and bad examples of software. Preservice teachers mentioned the ideas that software should be engaging or thought-provoking, help students participate in the processes of science, be age appropriate, be stereotype free, help build community, be seamlessly integrated, and have some connection to the real world. They also mentioned that good examples included StarryNight™, dissection software, data-gathering tools, ask-a-scientist Web sites, and e-mail collaborations. Bad examples included software that is "drill-and-kill," software that has no substance, and software that is used as an add-on.

Preservice teachers also discussed in small groups how they might incorporate technology into their curriculum project. Furthermore, we engaged in a whole-class debate about the merits and drawbacks of computer software in schools. Specifically, we debated whether or not to fund technology projects in schools or use those funds elsewhere. While this kind of activity illustrated generic issues of technology (and the outcome of this activity indicated that there was no longer a debate among preservice teachers as to whether or not technology should be incorporated into the classroom, as most of the preservice teachers thought it was important to help their future students become technology-literate), it began to frame some of the issues about how to infuse technology and to what end.

Exploring, Critiquing, and Using Modeling and Simulation Software

The final project in the course involved preservice teachers spending approximately 4.5 hours of class time conducting an in-depth investigation or review with a partner of one of five modeling tools chosen from our Web site (http://ott.educ.msu.edu/2002pt3/INDEX.HTM). As part of this investigation, preservice teachers explored their software, evaluated the software according to certain criteria, wrote one lesson plan using the software, and taught another pair of students about the software they had learned. The rationale for this portion of the intervention was to help preservice teachers learn about and use some often-inaccessible modeling and simulation tools to expand their vision of the kinds of software available. Furthermore, it was meant to give preservice teachers practice using these tools, critiquing them, incorporating them into lessons, and thinking about the role of those tools in science and science teaching.

To frame this work, Schwarz told preservice teachers that modeling lies at the core of science; that computer-modeling tools have revolutionized modern science and engineering and have shown great potential for helping in science education;

and that there are some good, but often inaccessible, modeling tools available for teachers and students. She also spoke about what models are (and defined a model as any representation that can help you predict and explain). She then explained that in this final project, the preservice teachers would be exploring a piece of software, evaluate it, design a short lesson around it, and teach this lesson and information about the software to another pair of students in the class.

Preservice teachers also received a handout reiterating the goals and nature of the project and some directions for how to navigate our Web site and choose the software. Part of this process asked students to read more about scientific modeling and think about why they were being asked to explore scientific modeling software. This direction sheet also gave more specific instructions for how to explore the software and how to evaluate it.

Preservice teachers then chose from among five modeling tools to review and evaluate, including ThinkerTools™ (force-and-motion; White & Frederiksen, 1998; http://thinkertools.soe.berkeley.edu/), Model-it™ (relation-based; Spitulnik et al., 1999), Archimedes & Beyond™ (matter; Smith, Snir, & Raz, 2002; no Web site), Models of Matter™ (matter; Smith, Snir, & Grosslight, 1992; no Web site), or MARS™ (matter; Raghavan & Glaser, 1995; no Web site). ThinkerTools™ is a microworld environment that allows students to run simulations of moving objects and observe the affects of various forces, such as impulses, gravity, and friction. The software runs according to Newtonian laws, but can be altered to run according to various other laws of physics. Students can run previously created simulations or create new microworlds they have created to test ideas about forces and motion. Model-it™ allows students to build and test models using relationships between dependent and independent variables. Students can use this program to model any causal relationship. As models are tested, students can change variables and relationships to examine the interactions taking place between objects or phenomena. Archimedes & Beyond™ aims to help students develop understanding of density. The software allows student to interact and view multiple macroscopic models of density (from qualitative intensity shading models to more quantitative models) to account for observed phenomena of mass–volume relations. Models of Matter™ simulates three laboratory experiments to help middle school students gain a better grasp of the nature of matter. Finally, MARS™ is designed to help students interpret, use, identify, and (in some cases) test computer models for understanding abstract physical concepts related to area, volume, mass, density, interaction properties, force, equilibrium, and weight.

Preservice teachers spent about 3 hours exploring the software both in class and at home. Because they experienced difficulty in learning and using the software, we circulated around the groups in class, coaching them on how to use the tools, teach them about particular features of the tools, and guide them if the software crashed. During this time, we engaged in constant dialog with preservice teachers, both in small groups and as a whole class, about benefits and drawbacks of the software and about the purpose of the software.

Preservice teachers then provided a general description of the software and evaluated it according to specific criteria, such as a description of the user's affective and cognitive responses to the software; the potential uses of this software; an evaluation of the artistic, technical, and pedagogical qualities of the software); and other criteria (including addressing some of the conditions we had previously generated in class, modifying the use of the software for younger and culturally diverse students, and learning about the preservice teachers' personal experiences with the software). Preservice teachers were also told that they must develop a short lesson plan that would incorporate the software into some science lesson. A representative sample of three student teacher evaluations and lesson plans can be found on our Web site.[3]

Preservice teachers subsequently paired up to teach one another about their software, taking roughly 45 min to engage their peers in an activity using the software and in teaching them about the nature of the software. The instructor, Schwarz**,** also encouraged preservice teachers to discuss the benefits and drawbacks of the software and compare them with the software used earlier in the course, as well as to think about how using the software might change how students learn science and under what circumstances they would think about using such software. This was perhaps the most generative portion of this set of activities as preservice teachers took ownership of the software and were evenhanded in their evaluation and use of the software.

We engaged in a final class discussion about the software by summarizing the advantages and disadvantages of the different pieces of software, reiterating why preservice teachers were exploring the software, and discussing how using this software might change how students learn science (e.g., what is the software trying to teach students about science?) They were told that it was hoped that this experience (among others in the course) would help them come to think about science and science learning as creating and revising scientific models within a community of practice—focusing on both the process of science and the habits of mind that operate in that community when using the tools and practices of the scientific community.

As a context for understanding the results, we present a paraphrased paragraph of the Schwarz's final comments in the last class discussion about the software that illustrates how she summarized the goals of the project.

> *Using the software can change our thinking about how science is learned and taught. Often, teachers and people think of science as a process of discovery—about manipulating materials and the ideas will come to you. In many instances, children will not change their ideas about science from experiencing science this way. I've seen all of you move toward thinking of science as a process of conceptual change—thinking about helping students learn to think for themselves about the world. I'm hoping that you will move toward this perspective that goes beyond teaching the right answers. Science is a lot more than just getting kids to the right answers and having them apply those answers. It's not always clear that, when they leave the classroom, the authority source that you've given*

[3] http://ott.educ.msu.edu/2002pt3/INDEX.HTM.

them will always exist. We have to be making decisions in society about things we don't have the answers for, like global warming or stem-cell research. We have to figure out what the best models are based on the information that we have. Using this software was a way to get you to think about it as a process of modeling—creating, using, and revising [models]. This issue really came out when we were using Model-it because the software doesn't give you the right answers. That could certainly be a disadvantage—kids could be reinforcing their misconceptions. But this happens in real life. There are other ways you can deal with this. You can think about what criteria could be used to come up with the best models or have kids compare and contrast models. This doesn't mean that . . . the content is[n't] . . . important, but it's more than just content—it's about the processes and habits of mind that this software helped you think about in a richer and more complex way.

Subjects and Methods

Twenty-five seniors (22 females and 3 males) in the Schwarz's elementary science methods course during the Fall 2002 participated in this study. This methods course often represents these seniors' second education course in a 5-year program for which the 5th year is the internship–student-teaching year. We used a variety of data sources for our analysis. Those data include a written pre- and posttest, videotapes of classes, journals, lessons plans and other work, and hour-long interviews with 10 preservice teachers after the end of the semester.

Preservice teachers took the pre- and posttest on the second- and final-class days. This paper-and-pencil assessment asked them questions about science content, the nature of science, their views of teaching science, the nature of science learning, and their understanding of scientific modeling. Sample questions included "What do you think is the best way to teach elementary science so that students will understand what science is and how science is done?"; "List three or four ways you might use computer software in your elementary science teaching"; and "How do you think computer models and scientific models can be useful for scientists, for teachers, and for learners?" The items from this pre- and posttest can be found on our Web site.[4] Additional data included videotapes of classes for which preservice teachers were using the software or discussing technology, student journals with responses to questions about the role of technology and what makes good software, and student lesson plans and computer software evaluations.

Finally, we conducted student interviews with 10 students up to 3 months after the course ended. These hour-long, postcourse interviews with one of the three authors of this paper were designed to determine preservice teachers' beliefs, goals, and understanding of technology, as well as their understanding of the nature of science, science learning, and science teaching. In particular, we asked preservice teachers what they thought about technology and integrating technology into the

[4] http://www.msu.edu/ ~ cschwarz/.

classroom; what they thought was good about technology; and what were they looking for; what they understand about the nature of science, inquiry, and modeling; and what they thought was important to teach in science and with what kinds of methods. The interview protocol can be found at our Web site.

Those data were analyzed in several ways. We analyzed pre- and posttests by coding responses to individual items. Jason Meyer, the second author, derived coding schemes that emerged from preservice teacher responses to a particular item (Glaser, 1992; Strauss & Corbin, 1990), then categorized and quantified student responses according to the coding schemes for each item. For example, when preservice teachers were asked, "What are some good examples of computer software that can be used for elementary science teaching? What makes them good examples?" he used preservice teachers responses to create an emergent coding scheme that included such categories as "interactive and fun," "explains difficult concepts" and "shows something that cannot normally or easy be observed." Preservice teachers' item responses could have been given multiple codes depending on how many of the codes the individual mentioned in their response. Numerical tallies of those pre- and posttest codes for each item enabled us to determine the type of overall preservice teacher response at the beginning and end of the course, as well as to determine whether or not there was any change in the frequency and types of responses after the course ended.

We transcribed and analyzed several portions of classroom videotape. In particular, we analyzed video from the final few class sessions to illustrate how Schwarz discussed issues of technology, pedagogy, and epistemology with the preservice teachers. We also analyzed a video of six preservice teachers teaching each other about the software to determine what aspects preservice teachers highlighted about the software for one another and how their ideas about the software manifested themselves through classroom talk toward the end of the course. A transcript of that conversation is available on our Web site.

We analyzed preservice teachers' journals by noting trends in comments related to technology, pedagogy, and epistemology to determine how preservice teachers' ideas evolved over time or may have been impacted by certain class experiences. For example, we examined how preservice teachers wrote about technology after they had read and discussed some of the readings about technology. We also noted instances when preservice teachers wrote about their experiences using software throughout the course and what they saw as good science teaching.

In analyzing lesson plans, we used the Bruce and Levin (1997) framework for determining how preservice teachers used the software. We also added two additional categories to this framework: (a) learning software for its own sake to "gain a better working knowledge about computers and how to use them" and (b) using computer software as a teaching tool for reinforcing and applying abstract concepts, not as a tool for conducting inquiry or building theories (perhaps similar to Bruce & Levin's teaching media category). We noted that lesson plans often received multiple codes. Schwarz and Ajay Sharma, the third author, cross-coded all 13 lesson plans for consistency and reliability. Analysis of the lesson plans indicated how preservice teachers thought modeling and simulation software should be used in their future classrooms at the end of the methods course.

Lastly, all interviews were transcribed, coded, and analyzed according to themes related to technology, epistemology, and pedagogy. For example, we derived emergent codes (Glaser, 1992; Strauss & Corbin, 1990) related to technology, such as whether or not the preservice teachers focused on design and aesthetics of the software or whether or not they emphasized the use of the software as visual or simulation tools, rather than as modeling or thinking tools. Similarly, we coded pedagogical and epistemological aspects of the interviews, such as how the preservice teachers discussed the purpose of the software for science teaching; if that purpose involved providing facts and information; and if the software should be used peripherally, rather than as a primary component of the course. In addition, we coded for additional emergent factors, such as if the preservice teachers mentioned goals for technological literacy for their own students or if they desired more guidance in interacting with the software. We determined the frequency of those codes throughout the interviews and chose excerpts from those interviews that best illustrated preservice teacher thinking as it related to those themes. Analysis of these data gave an overall indication about what preservice teachers thought about technology, pedagogy, and epistemology after the course ended.

Results

What did preservice teachers learn about educational software from this intervention and how did the intervention impact their views of science pedagogy and understanding of scientific epistemology? How did their views affect their evaluations of the software? Several results emerged from analysis of written pre-and posttest assessments, weekly student journals, videotapes of classroom conversations, and interviews with preservice teachers.

The Opportunity of Using Computer Modeling and Simulation Tools: Expanded Understanding About the Role of Technology and the Types of Technology Available

Data indicated that preservice teachers' experiences in this intervention expanded their understanding of the kinds of software available for science teaching. They began thinking not only of teaching media, but also moved toward thinking about media for inquiry. Moreover, preservice teachers expanded their ideas about the role that technology can play in the classroom, from thinking of technology as a source of information and a tool for clarification, to helping in conducting research and creating models.

Analysis of pretests, student journals, and videotapes from the beginning of the course shows that preservice teachers began with a positive outlook about technology, but little concrete knowledge. Preservice teachers felt it was very important for their students to be technologically literate (to be "able to use technology in general") and comfortable using technology, but they had little specific information for how one might use technology with students or help them become technologically literate, particularly in science. For example, when asked the question on the pretest, “What are some good examples of computer software that can be used for elementary science teaching? What makes them good examples?” 9 of 25 students were unable to provide examples of any good software programs to use in science class. Some preservice teachers had vague notions that software could be used for experimentation or to explain difficult concepts; others mentioned that it should be interactive and fun. Additionally, when asked on the pretest, “List three or four ways you might use computer software in your elementary science teaching,” the most common responses were using software to find information (11) and showing students things they couldn’t otherwise see or helping them visualize ideas (6).

In contrast, data from the posttests and interviews indicated that, as a group, preservice teachers had a more specific understanding of the kind of technology available for science instruction and a more elaborated understanding of the role of technology in teaching. Posttest scores indicated that 19 of 25 preservice teachers mentioned StarryNight as a good example of computer software, while many others mentioned names of additional software (Riverdeep ZAP!™; 5); Sammy Science House™ (5; http://www.riverdeep.net); ThinkerTools™ (5; http://thinkertools.soe.berkeley.edu); Model-it™ (4), and so forth. More important, while 4 preservice teachers still mentioned the importance of software’s being interactive and fun and 5 mentioned the importance of the software’s being easy to use, 13 preservice teachers wrote about how good software can show something that cannot normally or easily be observed (none mentioned this in the pretest) and 5 others about the importance of software that allows for manipulation (none mentioned this in the pretest). Further, when asked on the posttest, “List three or four ways you might use computer software in your elementary science teaching,” the most common responses included simulations (7), research (5), use or develop models (4), and help students conduct experiments (4), which is a shift from preservice teachers’ thinking of media as tools for communication toward thinking of tools as useful for conducting inquiry.

Eight of 10 interviews provided evidence of preservice teachers’ expanded understanding of technology. For example, one student stated,

> *I think definitely the most valuable [aspect of this project] was opening up my eyes, seeing how [technology] can help and aid in the classroom, especially bringing the technology into the field. I was really surprised that we did that, and it was so successful.*

In support of this statement, another student teacher stated,

> *The only software I was really familiar with [before this class] were the game-type pieces. These [experiences with the software from class] helped me see the different types of software that are available and that I wouldn’t have had a clue about. Now I feel like I have a better understanding of what to look for. If I did decided to use software in my classroom, I would know not to just go look for an educational game. I’ll look for things that actually teach something or will really be beneficial.*

Yet another student teacher stated,

> *I realized that [educational software] . . . existed, but I guess I didn't think about using them in my classroom just because I hadn't seen any. But now, I definitely think that I want to use technology in my classroom, especially like ThinkerTools, because it is really pretty simple, but it is really effective, you know. . . . [This experience] exposed me to technology in the fact that I could use it in my classroom. It showed how easy it would be to use something that simple for the students. So, I guess, just the exposure and experience with that.*

Preservice teachers also rethought the role of technology in their teaching, such as the preservice teacher who mentioned in the final interview,

> *Software can play a huge role if it's used correctly. If the kids get meaningful information from it or meaningful application, then it's definitely invaluable to them, especially software that you can manipulate. Then they can see that they can control things that they normally can't in the natural world.*

What experiences might have led to such changes and outcomes? Experiences with the computer software used in conjunction with the science investigations helped to expand preservice teachers visions of the role of technology in science teaching, as did the readings and the exploration of the modeling software at the end of the semester. For example, at the beginning of the semester, preservice teachers found StarryNight particularly useful and easy to use within their investigations of solar motion. One preservice teacher mentioned in the postinterview,

> *The Starry Night program was really great. I really enjoyed it. I thought it was pretty useful. You can use it in the classroom; [you] can get pretty good information from it; the graphics were good. It [does] a great job of showing what you might not necessarily see on a day-to-day basis.*

Furthermore, the readings presented a variety of software available for teaching science and linking technology to lesson topics. Preservice teacher journals written in response to these readings earlier in the semester indicated that they were able to learn about examples of computer technology in science teaching that included inquiry and communication media. They most often mentioned using tools that would show children something they would otherwise not be able to see (inquiry or teaching communication), using the Web to gather information (inquiry—data collection), and using e-mail for communication with scientists and other children (communication). Finally, the modeling and simulation software evaluation and teaching activities enabled preservice teachers to interact, evaluate, and teach by using theory-building simulation and modeling software not commonly available to teachers. This undoubtedly expanded their understandings of the type and role of technology in science teaching.

The Challenge of Using Computer Modeling and Simulation Tools: Misaligned Goals and Expectations for Computer Software Use

Perhaps the most striking finding of this study was that preservice teachers' goals and expectations for computer software were distinctly misaligned with the strengths and purposes of the modeling software they explored. Analysis of classroom discussions and interviews indicated that preservice teachers valued software that was fun, aesthetically pleasing, easy to use, and provided a source of scientific information within a clear and familiar learning task. The research-based modeling software they explored, while offering significant learning opportunities for students, was somewhat unstable, sometimes looked old, and did not always provide scientific information (e.g., Model-it™, which allows students to make relationships between variables, but does not assess the accuracy of those relationships). Throughout the semester, preservice teachers responded most favorably to the commercially produced computer software that was aesthetically pleasing, stable, provided accurate information, and fit in with a clear learning goal. At the end of the semester, preservice teachers remained highly skeptical of the value of research-based modeling tools—particularly the ones that did not impart direct scientific information, that looked old, that were sometimes unstable, and whose purpose and benefits were either unfamiliar or unclear.

To illustrate these expectations and the mismatch that occurred, 6 of 10 preservice teachers interviewed mentioned that software should be fun and aesthetically pleasing. For example, one stated, "[Software] should be . . . something that children are going to find educational but also fun—and keep their attention." Another stated, "We thought that for use in a classroom, we would need something that is visually more interesting [than the software we used]." Yet another stated, "[In using the software], I thought there would be more—like a big Bang, like Woo! Little cartoons running around or something." Perhaps the preservice teachers' focus on using materials that are fun and aesthetically pleasing was a response to feeling responsible for entertaining students who are used to being entertained, particularly with computers. It may also be related to their lack of experience with and understanding of the nature of science.

Five of 10 preservice teachers also mentioned that they would want to incorporate software in their future classrooms that was easy to use. "[Software] should be easy enough for the teacher and the user to use and understand . . . " It is reasonable that preservice teachers would want such software, given how many teachers have to function without much computer support in their schools and may not be very knowledgeable about computers and software.

Thirdly, we found evidence throughout the last classes—particularly in response to using the Model-it™ software—indicating that preservice teachers wanted software to provide concrete and accurate information for students to learn. "[Software] needs to shoot down misconceptions and . . . not create new ones. It needs to be on the students' level and . . . not too complex." "I like [Starry Night^{TM}] . . . I feel like it gives you concrete information . . . scientific information and facts." "[When I was using Model-it^{TM}] I was, like, this is so unfair. There are no specific answers. I could be doing this all wrong, my end result—who knows if it's right?" We found this pattern expressed frequently throughout the last classes, particularly in response to using Model-it^{TM}.

Student teachers' need for informational software indicated that they had difficulty seeing computer software as a beneficial tool for helping students externalize, visualize, and refine their own science ideas and theories. This may be a result of their traditional notions of teaching (the teacher and supporting materials should provide information for students to learn to eliminate misconceptions) and their ideas of software as needing to function in this respect because they may not have understood or experienced the software as functioning effectively for their own science-theory building. Perhaps their own lack of subject knowledge in science caused them to fear being responsible for helping children advance their theories without a source of authority for verification. When asked during the interview about what she might look for in future software for her classroom, one student summarized all of these factors in her response by stating,

> *Apart from [grade-level appropriateness], I would have to look for the aesthetics desirability of the software, the ease of use, the concepts that the software is trying to convey. . . . Obviously, [educational software] can't be misleading. It has to be interesting and educative. It should be enjoyable, working on it shouldn't look like a task or chore that [students]. . . are expected to do.*

In retrospect, we found some evidence that the context of the computer software use and exploration effected how preservice teachers responded to the software. In particular, preservice teachers responded most favorably to software that had clear functions and benefits. For example, using the software within the context of the science investigations was somewhat more effective at enabling preservice teachers to see and reflect on the functions and benefits of the software than exploring software on their own (even with the software curriculum materials and our tutoring). It appears that some preservice teachers may have needed a specific science context to help them understand the functions and benefits of these often-unfamiliar kinds of software. While we had suspected this might have been the case, a one-semester methods course limited our time for providing preservice teachers multiple experiences with software within science investigations.

The Opportunity of Using Computer Modeling and Simulation Tools: Challenging Ideas

While we found that preservice teachers' goals and expectations for computer software were significantly misaligned with the strengths and purposes of the modeling software they explored, we also found that the dissonance between preservice teachers' goals and the purposes of the software challenged pedagogical and epistemological thinking and provided a fruitful platform for discussions around those ideas. In other words, the dissonance between student teachers' expectations for software and their reactions to the qualities of the modeling and simulation software exposed the fact that preservice teachers still held strong pedagogical frameworks (that were not model-based inquiry, but, perhaps, more teacher directed and entertainment focused) in which they were looking for the computer to impart scientific information while providing fun and engagement. The dissonance preservice teachers experienced while working with these tools became a learning opportunity for our class by helping us engage in conversations about what should be taught in science and how. These conversations then challenged preservice teachers' ideas to think about the nature and goals of science teaching and the role of scientific modeling.

Three preservice teachers, particularly those who worked with Model-it, spoke of their struggles for rethinking the purpose of computer software in science teaching and about science teaching in general during the interviews. For example, one preservice teacher stated,

> *I expected there to be a clear-cut right or wrong experiment . . . [in this computer model] and the computer would say, "This is impossible because in the world you can't do this." . . . But then [our instructor] question[ed] it. . . . [She said], isn't it beneficial . . . to go through the . . . process [of creating models]? . . . I think she's actually right. . . . Just because it doesn't give you . . . a specific [answer] . . . it is still beneficial to use in the classroom.*

Yet another preservice teacher stated,

> *I just expected . . . more . . . like, the computer will tell you what to do. You will get more directions. . . . So after we had built the cause-and-effect [model on the computer], we realized that the information wasn't accurate. . . . So my first reaction right away was, "This isn't any good because it is giving false information. I think if children see it, they would believe it. Even though it is on the computer and something that you created. . . . Then I talked to you [the instructor] and you pointed out that . . . [using the tool] could be about the process. . . . That made a lot more sense as I started looking at it differently. But then I wouldn't want children to also get this false information. And I am sure that if it was explained right, then it could be worked through. . . . Yeah, [having different groups of kids argue with each other about which of the models was best or checking each other's models to point out their problems] would be good.*

Again, helping preservice teachers think that the value and purpose of theory-building tools may involve rethinking their own goals and purposes of science teaching (pedagogy) and their understanding of the nature of science (epistemology).

Analysis of Final Technology Lesson Plans. Analysis of final technology lesson plans and transcripts in which preservice teachers taught each other about the software provided some evidence of preservice teachers' conflicting notions about technology and pedagogy, and it indicated how the preservice teachers struggled with the nature of purpose of the computer software and science teaching. Final technology lesson plans (in which preservice teachers used the software within a lesson that they might teach to their own future students) and analysis of the one unit plan during the semester in which the preservice teachers used educational software showed that the majority of preservice teachers (8 of 13 lesson plans) used the software in an inquiry-based, theory-building way. For example, one preservice teacher designed a lesson with *ThinkerTools*™ in which he stated,

> *The children will work in pairs on computers using the ThinkerTools™ software. Each pair of kids will hypothesize whether or not two objects of the same or different masses will fall at the same speeds. The kids will then set up an experiment on the ThinkerTools™ software to test this hypothesis.*

Nonetheless, analysis of these lesson plans also suggested that preservice teachers had conflicting notions about the purpose and nature of these tools within an inquiry context. For example, six lesson plans indicated that the preservice teacher envisioned using the software as a way to help students apply and practice the concepts, not as tools for theory building. One preservice teacher stated in her lesson plan, whose lesson objective was to "reinforce the concepts of mass, volume, and surface area" that

> *Children will be in pairs at a computer and will have a worksheet to complete. The worksheet will consist of different areas, volumes, and surface area. The children will have to write down what lengths and widths that they found to create these different masses, volumes, and surface areas.*

Furthermore, four lesson plans involved using the software as a communication tool, either as a device to help the teacher communicate the concepts to students or as a student assessment. We even found in one student's lesson plan that she used the software as a tool for construction in which she asked students to build their own skyscrapers! For more complete examples of final lesson plans, see our Web site.

Analysis of Student Conversation About the Software. We also found evidence of this pedagogical and epistemological conflict within conversation at the end of the semester as the preservice teachers taught each other about the software. For example, when analyzing transcript of three pairs of students teaching each other about the software [more complete transcript can be found on our Web site], we found that the preservice teachers often wanted to determine how to use the software in teacher-directed ways for demonstrating, applying, or assessing concepts. They also mentioned software aesthetics and ease of use. At the same time, these preservice teachers noted some of the benefits of the software for student exploration and investigation. For example, when the group discussed the software, Archimedes and Beyond, the preservice teachers spent time discussing that they "definitely would use the instruction" in telling students how to navigate the software and that they would "display it upfront" and "demonstrate it" before running the simulation or letting children "play around with it." The preservice teachers presenting the software also stated that the software was "very cute ... very basic" and "it is kind of fun," though "one bad thing is that the screen is so small." At the same time, the preservice teachers noted more substantial student-centered aspects, such as the purpose of the software for addressing ideas of density and volume and that they "thought it was the best ... "

Preservice teachers who presented Model-it™ struggled with similar issues mentioned earlier in this paper. The conversation among the preservice teachers revolved around how to understand and use the software in a more familiar, teacher-directed manner. For example, one of the preservice teachers stated, "I guess I just see the software as being more of helping students to understand and read graphs ... it is really not telling you anything new." To which others stated, "It is just a model"; "It is creating a modeling relationship"; and "[laughing] This is all it can do." One of the preservice teachers mentioned, "This isn't going to tell you if you are right or wrong," to which another responded, "You would have to have the knowledge." The conversation continued in which one of the preservice teachers stated,

> *If we left it to the students, they are going to come up with all the different answers ... which isn't necessarily bad; but then, maybe you should just focus on ... the graphs [or as an assessment tool to have students] build the relationships ... and see if they get it right in the graphs.*

At the same time, the preservice teachers stated that the software might be useful at the end of a unit to "have students look at it, and make causal relationships," and that while the software was not useful for recording data, but it could "simulate data faster than outside." The preservice teachers also mentioned to one another that the software was "kind of fun," and "a good way to learn."

Finally, students who presented ThinkerTools™ mentioned a similar set of issues. For example, they discussed that the software had so many variables, they should set up the environments for their own students before having their students work with the software. Later, they mentioned, "Kids can then sit there and watch the teacher manipulate everything and do everything, and then do it on their own." The preservice teachers also discussed more student-centered ideas that the software was "really nice" and enabled students to see the motion of objects, to change one variable at a time, and to see that the data are always consistent. Finally, they mentioned that the software was "really a simple-looking program" that "looks like one of those fun things where you draw and all."

Preservice Teachers' Struggles With Inquiry and Modeling. At the same time as preservice teachers struggled with notions about the nature and purpose of computer software and science teaching in their talk with one another, they struggled to understand the importance and connection between scientific modeling and scientific inquiry. On the one hand, some learned important aspects about both modeling and inquiry, as can be seen in their interviews and in their posttests. For example, five preservice teachers in the interviews understood models as tools to help people better understand abstract objects or phenomena:

> *[Models] show us what can't be shown in real life, or it's not practical. They allow the person to relate to what they can't experience in terms they understand.*
>
> *A scientific model is something that takes a broad idea and paints a picture for you of a difficult concept or breaks something down into parts. It's a way of helping understand something that might be a little more difficult.*
>
> *A scientific model is a representation of a theory or a concept or something that is not necessarily accessible to us. Like a sun dial is a model, a hard-boiled egg cut in half is a model of the earth's crust, ball and stick molecular configurations model molecules.*

At the end of the class, preservice teachers also were better able to identify computer simulations (17 of 25 pretest; 23 of 25 posttest) and equations as models (10 of 25 pretest; 15 of 25 posttest) and explain that some models are better than others because of their accuracy or thoroughness (4 pretest; 9 posttest) or because of clarity (0 pretest; 4 posttest).

Similarly, preservice teachers learned to think of inquiry as much more central to their practice of science teaching and fundamental to the nature and practice of science, though these understandings of inquiry were unlikely to be normative or robust: "Inquiry is really important—to raise questions and search after them." Preservice teachers also identified inquiry as an important goal in the posttest. For example, when students were asked on the pre- and posttest, "What aspects of science would you want to emphasize in your own elementary science teaching, and how much of each aspect would you want to teach? (Some aspects might include scientific concepts, scientific skills or processes, and scientific habits of mind and attitudes) Why?" There was a shift toward inquiry and some shift toward scientific habits of mind at the end of the course. In the pretest, 1 person mentioned "hands-on experiments," but no one mentioned inquiry. In the posttest, 3 preservice teachers mentioned hands-on experiments, and 6 mentioned inquiry. In the pretest, 10 mentioned scientific habits of mind, compared to 13 in the posttest.

Not surprisingly, however, 9 of 10 preservice teachers interviewed had difficulty understanding how to integrate ideas of scientific modeling and inquiry together and how to frame these within science teaching (even within the computer software as a basis to do so). In other words, they had difficulty conceiving of science and science learning as a process of creating and revising models using scientific tools within a learning community. For example, when preservice teachers were asked to think about how science is similar to model building, one student replied [after thinking very hard], "I don't know. I guess it is very similar. I don't know. I have no idea. I know there is a correlation there, but I really don't know how." We also note that none of the preservice teachers whom we interviewed spoke about the importance of using computer-modeling software for helping students engage in modeling or for learning how scientific modeling is done—though many spoke of using the software for simulating phenomena. In addition, most preservice teachers felt that they still did not have a good sense for what a scientific model was. Given that pedagogical and epistemological change is difficult and requires long-term exposure in multiple settings, this result was not entirely surprising. Others have found similar results (Cullin & Crawford, 2003).

The Challenge of Using Computer Modeling and Simulation Tools: Institutional Factors Affected Outcomes

In addition to the challenges of misaligned goals between the preservice teachers and the software, we found several additional factors that limited the impact of this intervention on advancing preservice teachers' thinking about technology, epistemology, and pedagogy. In particular, we found that such institutional factors as few samples of stable discipline-specific modeling software for elementary school science (though there are more at the middle and secondary level), no prior exposure to such an approach within discipline-specific courses, and lack of time within the course played a role in the impact of this approach. As such, we would hope that commercial software designers might consider creating and sustaining such theory-building tools for elementary science teaching and that science content courses would consider using modeling tools and simulation software in various similar capacities.

Current Work

Patterns in these results pointed to several recommended changes. For example, preservice teachers' difficulties integrating ideas for how to teach model-based inquiry using technology tools clearly indicated a need for a more coherent framework to clarify and structure this process. As a result, Schwarz created an instructional model (guided inquiry and modeling instructional model using technology) that was used and tested in a subsequent semester's course (Schwarz & Gwekwerere, 2007). Such a model was a revised version of the Biological Science Curriculum

Study's 5E model (Bybee, 1997) of engage, explore, explain, elaborate, and evaluate; and its use was successful at helping student teachers to reflect on and change their orientations about science teaching (Magnusson et al., 1999). We continue to refine and test such pedagogical tools for helping preservice teachers learn about modeling and inquiry by using technology. In addition, we continue to revise our theoretical framework to account for a richer and more accurate description of preservice teachers' development related to technology, epistemology, and pedagogy. Further, we continue to search for appropriate computer-modeling tools and ways of incorporating those tools for preservice teachers' own subject matter learning and their future subject matter teaching. Finally, our future research aims to investigate how teachers who take such a course are able to incorporate and enact these ideas in their own classrooms.

Summary and Implications

Overall results suggest that this technology integration using computer modeling and simulation tools provided some challenges and opportunities for helping preservice teachers learn about technology, science pedagogy, and epistemology. On the one hand, we found that that the use and discussion of such inquiry and theory-building tools expanded their understanding of the type and role of technology in science teaching; on the other hand, some of the modeling software (e.g., Model-it™) and contexts for learning the software (e.g., self-exploration) conflicted with preservice teachers' expectations for software that was fun, aesthetically pleasing, easy to use, and provided a source of scientific information within a clear and familiar learning task. As we discovered, some preservice teachers still held traditional notions of science pedagogy (that teaching science is about providing information) and epistemology (science is about learning and obtaining scientific information, not about building models and theories from evidence) and had difficulty understanding the purposes and benefits of modeling and simulation software for helping children build their theories. Nonetheless, this conflict of expectations and goals provided a fruitful platform on which to challenge preservice teachers' ideas about science pedagogy and epistemology. Lastly, lack of commercially-supported and stable software for elementary school science and the limited amount of time and no prior exposure in science content courses reduce the impact such an approach can have with preservice teachers.

To maximize teachers' understanding of technology, epistemology, and pedagogy, we consider the following recommendations for elementary science methods courses: (a) Infuse multiple uses of technology (including modeling and modeling software) within curriculum with transparent purposes and benefits, (b) connect preservice teacher's experiences of using such tools in their own learning of the content and nature of the subject matter with the affordances the technology might have for their own students,[5] (3) and use and study such additional tools as open-ended

[5] We note that perhaps using epistemic bridges, such as building physical or conceptual models, might help preservice teachers better understand the purpose and benefits of modeling and modeling tools.

modeling tools (e.g., programming environments) that may be particularly effective at challenging views about the role of computer technology. Examples range from the Model-it™ environment; to a programmable elementary tool, such as Squeak™ (squeakland.org); to the forthcoming Scratch™ (Resnick, Maloney, & Silverman, 2004); to a concept-mapping tool, such as Inspiration™ (inspiration.com). These tools should, of course, be incorporated within the context of science investigations within their own curriculum materials if at all possible. Similar tools, but more advanced, are essential in modern science and engineering and are more authentic tools for science learning.

Several policy implications can be made from this study. Coordinate subject area courses to address technology in ways that are pedagogically and epistemologically consistent with instructional models discussed and embodied in methods courses to help preservice teachers see the benefits and utility of all types of software and technology (Cullin & Crawford, 2003). Furthermore, teacher educators, school districts, and teachers themselves must create the demand for software publishers to produce software that enables more open-ended simulations and modeling environments for science teaching (with curriculum materials that address the standards and make it obvious what the purposes and benefits will be for helping students better understand the nature and practices of science). Advances in these areas may help improve teacher education courses, as well as help teachers become better prepared to use technology in the classroom while ultimately improving their science teaching.

Acknowledgments

The authors thank the preservice teachers in the elementary methods class who participated in this study, as well as Vijaya Rajagopalan who worked on the Web site. We also thank colleagues at Michigan State University who provided helpful feedback on this paper.

References

Becker, H. J., Ravitz, J. L., & Wong, Y. (1999). *Teacher and teacher directed student use of computers and software* (Report #3). Irvine: University of California, Irvine, Center for Research on Information Technology and Organizations (CRITO).

Bruce, B. C., & Levin, J. A. (1997). Educational technology: Media for inquiry, communication, construction, and expression. *Journal of Educational Computing Research*, *17*(1), 79–102.

Bybee, R. W. (1997). *Achieving scientific literacy: From purposes to practices*. Portsmouth, NH: Heinemann.

Carey, S., & Smith, C. (1993). On understanding the nature of scientific knowledge. *Educational Psychologist*, *28*, 235–251.

Cullin, M., & 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*, 409–426.

Driver, R., Leach, J., Millar, R., & Scott, P. (Eds.). (1996). *Young people's images of science*. Philadelphia: Open University Press.

Feurzeig, W. (1994). Preface: Special issue of interactive leaning environments on modeling and simulation in science education. *Interactive Learning Environments*, *4*, 193–194.

Feurzeig, W., & Roberts, N. (Eds.). (1999). *Computer modeling and simulation in science education*. New York: Springer-Verlag.

Gilbert, S. (1991). Model building and a definition of science. *Journal of Research in Science Teaching*, *28*, 73–79.

Glaser, B. (1992). *Basics of grounded theory analysis: Emergence vs forcing*. Mill Valley, CA: Sociology Press.

International Society for Technology in Education. (2003). *National educational technology standards*. Washington, DC: Author.

International Technology Education Association. (2000). *Standards for technological literacy: Content for the study of technology*. Reston, VA: International Technology Education Association.

Justi, R. S., & Gilbert, J. K. (2002). Science teachers' knowledge about and attitudes towards the use of models and modeling in learning science. *International Journal of Science Education*, *24*, 1273–1292.

Koch, J. (1996). Elementary school science and technology: A seamless connection. In L. Wolozin, L. Mafrici, & R. Bennett (Eds.), *Science stories: Teachers and children as science learners* (pp. 275–292). Boston: Houghton Mifflin.

Lehrer, R., & Schauble, L. (2000). Modeling in mathematics and science. In R. Glaser (Ed.), *Advances in instructional psychology: Vol. 5: Educational design and cognitive science* (pp. 101–159). Englewood Cliffs, NJ: Erlbaum.

Magnusson, S., Krajcik, J., & Borko, H. (1999). Nature, sources, and development of pedagogical content knowledge for science teaching. In J. Gess-Newsome & N. G. Lederman (Eds.), *Examining pedagogical content knowledge* (pp. 95–132). Boston: Kluwer Academic Publishers.

Martin, R., Sexton, C., & Gerlovich, J. (2001). How can you use educational technology to enrich your classroom? In N. Forsyth (Ed.), *Teaching science for all children* (pp. 392–421). Boston: Allyn and Bacon.

Mellar, H., Bliss, J., Boohan, R., Ogborn, J., & Tompsett, C. (Eds.). (1994). *Learning with artificial worlds: Computer based modeling in the curriculum*. Washington, DC: Falmer.

Morgan, M. S., & Morrison, M. (1999). *Models as mediators: Perspectives on natural and social science*. Cambridge, England: Cambridge University Press.

Passmore, C., & Stewart, J. (2002). A modeling approach to teaching evolutionary biology in high schools. *Journal of Research in Science Teaching*, *39*, 185–204.

Raghavan, K., & Glaser, R. (1995). Model-based analysis and reasoning in science: The MARS curriculum. *Science Education*, *79* (1), 37–61.

Resnick, M., Maloney, J., & Silverman, B. (2004). Scratch: Creating a "programming culture" at community technology centers. In Y. Kafai, W. Sandoval, N. Enyedy, A. Nixon, & F. Herrera (Eds.), *Proceedings of the sixth international conference of the learning sciences* (pp. 16–17). Mahwah, NJ: Erlbaum.

Sandholtz, J. H., Ringstaff, C., & Dwyer, D. C. (1997). *Teaching with technology: Creating student-centered classrooms*. New York: Teachers College Press.

Schwarz, C., & Gwekwerere, Y. (2007). *Using a guided inquiry and modeling instructional framework (EIMA) to support pre-service K-8 science teaching*. Science Education, *91*(1), 158–186.

Schwarz, C., Meyer, J., & Sharma, A. (2004). Preparing tomorrow's teachers to use technology: Analysis of pre-service elementary and middle school teachers' interactions with computer modeling and simulation tools. In Y. Kafai, W. Sandoval, N. Enyedy, A. Nixon, & F. Herrera (Eds.), *Proceedings of the sixth international conference of the learning sciences* (p. 633). Mahwah, NJ: Erlbaum.

Schwarz, C. V., & White, B. Y. (2005). Metamodeling knowledge: Developing students' understanding of scientific modeling. *Cognition and Instruction*, *23*, 165–205.

Smith, C., Snir, J., & Grosslight, L. (1992). Using conceptual models to facilitate conceptual change: The case of weight-density differentiation. *Cognition and Instruction*, *9*, 221–283.

Smith, C., Snir, J., & Raz, G. (April, 2002). Can middle schoolers understand the particulate theory of matter as an explanatory model? An exploratory study. Paper presented at the American Educational Research Association meeting, New Orleans, LA.

Spitulnik, M., Krajcik, J., & Soloway, E. (1999). Construction of models to promote scientific understanding. In W. Feurzeig & N. Roberts (Eds.), *Modeling and simulation in science and mathematics education* (pp. 70–94). New York: Springer-Verlag.

Strauss, A., & Corbin, J. (1990). *Basics of qualitative research: Grounded theory procedures and techniques*. Newbury Park, CA: Sage.

U.S. Department of Education. (1996). *Getting America's students ready for the 21st century—Meeting the technology literacy challenge: A report to the nation on technology and education*. Washington, DC: Author.

U.S. Department of Education. (1998). *Preparing tomorrow's teachers to use technology*. Washington, DC: Author.

VanDriel, J. H., & Verloop, N. (2002). Experienced teachers' knowledge of teaching and learning of models and modeling in science education. *International Journal of Science Education*, *24*, 1255–1272.

White, B., & Frederiksen, J. (1998). Inquiry, modeling, and metacognition: Making science accessible to all students. *Cognition and Instruction*, *16*(1), 3–118.

Windschitl, M., & Sahl, K. (2002). Tracing teachers' use of technology in a laptop computer school: The interplay of teacher beliefs, social dynamics, and institutional culture. *American Educational Research Journal*, *39*, 165–205.

Zhao, Y., & Frank, K. A. (2003). Factors affecting technology uses in schools: An ecological perspective. *American Educational Research Journal*, *40*, 807–840.