Developing Preservice Elementary Teachers' Knowledge and Practices Through Modeling-Centered Scientific Inquiry

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ABSTRACT: Preservice elementary teachers face many challenges in learning how to teach science effectively, such as engaging students in science, organizing instruction, and developing a productive learning community. This paper reports on several iterative cycles of design-based research aimed at fostering preservice teachers' principled reasoning around these problems of practice through modeling-centered scientific inquiry. The first design cycle introduced preservice teachers to modeling and simulation software tools in an effort to advance their understanding of science and technology; the second used an instructional framework embodying modeling-centered inquiry to advance their views of effective science teaching and their lesson-planning practices; the third engaged preservice teachers in analyzing and modifying curriculum materials using reform-based criteria to foster effective curriculum materials use. Outcomes from these iterations indicate that the preservice teachers were most likely to advance their knowledge and practices within a coherent approach that focused on a core scientific practice such as modeling-centered inquiry, provided opportunities to unpack and apply robust tools such as reform-based instructional frameworks, and addressed their perceived problems of practice. The findings from this set of approaches are compared to others in an effort to point toward promising future directions for effective science teacher education. © 2009 Wiley Periodicals, Inc. *Sci Ed* **93:**720–744, 2009

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INTRODUCTION

Preservice and beginning teachers face a number of challenges in learning how to teach science effectively (Appleton, 2006; Darling-Hammond & Bransford, 2005; Davis, Petish, & Smithey, 2006). These challenges include developing their professional knowledge about science content, scientific practices and discourses, and the nature of science (National Research Council [NRC], 2007) as well as their knowledge about learners' strengths, needs, and ways of knowing. At the same time, preservice and beginning teachers need to develop a repertoire of instructional techniques, strategies, and approaches (Feiman-Nemser, 2001) that can foster productive learning communities as well as professional visions and dispositions for effective teaching (Hammerness, Darling-Hammond, & Branford, 2005).

These challenges in learning to teach can also be framed as problems of practice (Mikeska, Anderson, & Schwarz, 2009, this issue). Beginning teachers need to learn how to address problems of practice such as engaging students in science, organizing instruction and developing productive learning communities—and in doing so, develop their knowledge, teaching practices, and dispositions. Preservice teachers recognize these problems of practice as important, though from a somewhat different perspective (Abell, Bryan, & Anderson, 1998; Davis et al., 2006; Howes, 2002; Schwarz et al., 2008). They want to engage their own students in interesting and real-world science information, teach science in a manner that is more fun, exciting and relevant than it frequently was for them as former students, and fix science misconceptions. Preservice teachers also want to manage their students' behavior to maintain organization throughout the class day and to build a repertoire of activities so they are prepared to teach science and other subject areas for the entire school year.

What are some effective ways of helping preservice teachers address these problems of practice to help them teach science successfully to meet new reform-based goals (NRC, 2007)? Any effective approach must be strategic as there is limited time and capacity for helping them become well-started beginners[1] for their own classrooms after completing their certification. Prior research offers some strategies for effectively preparing preservice teachers for teaching science (Appleton, 2006; Davis et al., 2006). Effective teacher education generally involves helping preservice teachers analyze teaching and learning within particular contexts such as their placement classrooms or with video and written cases, and giving preservice teachers opportunities to teach and reflect on their teaching with microteaching and field experiences that make use of performance assessments and portfolios (Darling-Hammond & Bransford, 2005). Prior research in science teaching, for example, has shown that engaging preservice teachers in multiple cycles of planning, teaching, and reflection can help preservice teachers organize teaching around important science ideas and better account for learners in that instruction (Zembal-Saul, Blumenfeld, & Krajcik, 2000). Furthermore, preservice teachers can build their repertoire of instructional techniques as well as their confidence by observing and discussing effective and enthusiastic science teaching (Rice & Roychoudhury, 2003). Nonetheless, the question remains: How can these strategies that range from general teacher education strategies to specific science method techniques be synthesized with teaching and learning frameworks to create coherent, effective approaches for elementary preservice science teacher education?

[1] As the introductory paper states, well-started beginners have less professional knowledge than experts, but are capable of using their knowledge to focus on key learning issues that arise in classroom practice and to make curricular and instructional decisions.

APPROACH

It is an assumption of this paper that one effective approach for preparing preservice elementary teachers to teach science is to focus on key aspects of reform-based science teaching. In my work, this focus has been on the scientific practice of modeling-centered inquiry. In particular, my goals have entailed helping preservice teachers address problems of practice by advancing their knowledge about modeling-centered inquiry, reformulating their views of effective science teaching to include modeling-centered inquiry, and developing their pedagogical knowledge and teaching practices using tools such as technology, frameworks, and curriculum materials that can support reform-based teaching. An important aspect of addressing these goals is enabling preservice teachers to experience learning and teaching science using modeling-centered inquiry in a productive learning community.

What is modeling-centered scientific inquiry? A modeling-centered inquiry approach is an instructional approach in which learners engage in scientific inquiry whose focus is on the creation, evaluation, and revision of scientific models that can be applied to understand and predict the natural world (Lehrer & Schauble, 2000; Schwarz & White, 2005; Stewart, Cartier, & Passmore, 2005; Windschitl & Thompson, 2006). In other words, the practice may begin with a question and an initial model that is being tested. For example, the question might be "What causes a shadow?" and the initial model might entail a shadow caused by a light and an object. This is followed up with investigations of phenomena that generate data. For example, one could investigate conditions of existing shadows as well as the conditions needed to produce shadows. Those data are subsequently analyzed for patterns and then used as evidence to support or disprove aspects of a scientific model. In this case, the model could be refined to include a surface on which the shadow is projected and a light source that emits direct light rather than diffuse light as well as an unblocked path for that light to travel. After revising those models to account for patterns in data and canonical scientific constructs (such as the notion of light traveling as light rays), those models can then generate multiple explanations for other phenomena such as why clouds sometimes make shadows or the most effective ways to play shadow tag. A modeling-centered inquiry approach also includes a focus on understanding the nature and purpose of modeling-centered inquiry such as helping learners understand that modeling-centered inquiry is a dynamic process that involves iteratively revising models to be consistent with theory and evidence and that models can be used to predict and explain multiple phenomena in the natural world (Schwarz & White, 2005; Schwarz et al., in press).

In this sense of the term, models are representations that abstract and simplify a system to make its central features explicit (Gobert & Buckley, 2000). They consist of elements, relationships, operations, and rules that govern the interactions (Lesh & Doerr, 2003). They can be classified into two types: internal models and expressed models (Gobert & Buckley, 2000). Internal or mental scientific models refer to the individuals' internal representation of the explanatory mechanisms or predictive patterns and laws that underlie particular natural phenomena (e.g., one's mental conception of matter as consisting of moving particles). Expressed models can be thought of as the external representations of internal models (e.g., an external representation of matter using ball-and-stick diagrams of atoms and molecules). In my work, I primarily refer to expressed scientific models or tools for embodying or expressing aspects of scientific theories (internal models) in a form that can be used to illustrate, explain, or predict an object or phenomena—for example, to characterize what happens as time passes or as events occur. Expressed scientific models can range in form from physical representations (like a globe) to diagrammatic models (life cycle of animals; particle model of evaporation), to computational and mathematical models. Taken together, internal and expressed models are essential components and products of scientific inquiry as well as essential tools for scientific reasoning.

Modeling-centered scientific inquiry is a fundamental scientific practice that encompasses the investigative nature of science as well as the product of the investigation—models that can generate multiple predictions and explanations about the world. Furthermore, modeling-centered inquiry is a powerful practice for science learning and learning across disciplines. Focusing on such a practice can help learners understand the nature of disciplinary knowledge and how to develop and use such knowledge. For example, inquiry-based approaches can help learners develop deeper understanding of subject matter, scientific skills, and habits of mind (NRC, 2000). Models and modeling can help learners build subject matter expertise, epistemological understanding, and practices and skills such as systems thinking (Lehrer & Schauble, 2000; Lesh & Doerr, 2003; Schwarz & White, 2005). Furthermore, engaging learners in modeling-centered inquiry can help them develop their scientific literacy—deepening their scientific knowledge through generating, evaluating, and revising their thinking in a community of practice so that they can make more informed personal and societal decisions and more effectively participate in the world.

Nonetheless, most teachers have limited experience and knowledge about scientific modeling or modeling-centered inquiry (van Driel & Verloop, 1999, 2002; Windschitl & Thompson, 2006). Teachers often see models as useful for teaching information about scientific content, rather than as tools within a scientific process that can help learners understand the nature of science (Crawford & Cullen, 2004; Henze, van Driel, & Verloop, 2007; Justi & Gilbert, 2002) or as thinking tools that can advance students' model-based reasoning (Harrison & Treagust, 2000; Henze et al., 2007). Furthermore, when teachers do engage their own students in modeling, there is much variation of use (Harrison & Treagust, 2000) and limitations on the epistemological richness of the pedagogy (Justi & Gilbert, 2002) such as simplifying model-based inquiry to a variation of the "scientific method" (Windschitl & Thompson, 2006).

While teaching using modeling-centered inquiry can be challenging, a pedagogical approach that focuses on modeling-centered scientific inquiry has the potential for helping teachers understand more about science, science practices, and the nature of science. In can also help support an effective reform-based vision for science teaching as an alternative to common discovery or didactic approaches to teaching elementary science (Roth, 1991) while providing a beginning repertoire of pedagogical approaches and strategies. As such, modeling-centered inquiry may be able to help preservice teachers address some of the problems of practice that they face. Because of both the challenges and the affordances of modeling-centered inquiry pedagogy, beginning teachers need support to effectively engage their students in this practice (Crawford & Cullin, 2004; Justi & Gilbert, 2002; Schwarz & Gwekwerere, 2007; Windschitl & Thompson, 2006; Windschitl, Thompson, & Braaten, 2008).

To foreground modeling-centered inquiry in teacher education is not to imply that other foci of teacher education such as learning about students and forming a reflective teaching disposition are less important. Beginning teachers need to learn how to establish an effective learning community and understand all their students in order to be responsive to their needs and strengths in the classrooms. Beginning teachers must also start to develop a productive teaching orientation that involves a critical disposition, a level of self-confidence, and some willingness to engage in adventurous teaching as they navigate among different communities of practice. These are essential components of teacher education that must be directly addressed and developed.

Nonetheless, it is important for preservice and beginning teachers to have a clear, well-founded goal for student learning and participation within science subject matter—which is why I focus on modeling-centered scientific inquiry. Meaningful and intellectually substantial content is essential for effective learning communities—as learners deserve to have access to the beauty and power of scientific ways of knowing the world.

As a result, this paper reports on several cycles of design-based research aimed at developing preservice elementary teachers' knowledge and practices of modeling-centered inquiry. The goal of this work is to use the outcomes from this research to determine effective approaches for science teacher education that address problems of practice and advance preservice elementary teachers' knowledge and practices in teaching science.

TEACHER CERTIFICATION PROGRAM AND PRESERVICE TEACHER PARTICIPANTS

As the remaining portion of the paper describes my efforts in working with preservice teachers in my institution's teacher certification program, I will briefly describe the program and the preservice teachers' general experience. Students enrolled in my institution's elementary science methods courses are typically college seniors. This science methods course is usually their second or third education course within a 5-year program for which the fifth year is their student teaching or internship year. The course includes a field component in which preservice teachers observe and participate in elementary classrooms for 5 hours a week. As part of the methods course, preservice teachers prepare and teach several lessons in each content area within their placement classroom. For example, during their senior year, a preservice teacher might teach two science lessons and one social studies lesson in the fall, and two mathematics lessons and three language arts lessons in the spring. Preservice teachers also take a second science methods course during the second semester of their internship (not reported in these studies) to support them in teaching their science lessons in their placement classrooms and to reflect on that learning.

To better understand how the preservice teachers learn how to address problems of practice such as engaging students in science and organizing instruction with modeling-centered inquiry, there are a few other dimensions of preservice teachers that are helpful to describe further—their notions of good science teaching, their participation in various communities of practice, and their views of or orientations toward effective teaching practices. Preservice teachers in our program as well as those in others (Abell et al., 1998; Appleton, 2002) frequently begin the elementary science methods course with strong intuitive notions of science teaching as either an "activity" or "discovery-based" approach involving hands-on experiences to get students excited about science, or as a "didactic" approach involving teacher lecture or text and worksheet use to eliminate ("fix") or prevent misconceptions (Roth, 1991). Sometimes, preservice teachers hybridize the discovery and didactic approaches to one that involves telling or reading students the science ideas and reinforcing those ideas with fun, hands-on activities, and worksheets. While the preservice teachers in our program have learned some science content, preservice teachers tend to view science as a body of facts and information that can be taught and learned through knowledge transfer and reinforcing activities. Few have had prior experiences with scientific inquiry, and still fewer know how to engage students in scientific practices or discourses—important aspects of the standards-based reforms designed to develop critical thinking skills in learners (NRC, 2007).

The preservice teachers in the program function within multiple communities of practice that have different or sometimes oppositional emphases and values in science teaching. For example, they participate in their science content courses in the science departments that typically emphasize conceptual and factual knowledge. They also participate in elementary methods courses in the education program that typically emphasize constructivist student-centered environments and scientific inquiry. Finally, they participate in the school placement classrooms in the elementary schools that typically focus on hands-on activities, worksheets, and information recall if they are fortunate enough to observe any science teaching. Furthermore, preservice teachers often have partial and sometimes inaccurate perceptions of their future teaching practice including lacking awareness of the significant role of curriculum materials in shaping their future science teaching. An approach for helping preservice teachers develop principled reasoning around problems of practice needs to take these dimensions of preservice teacher learning into account.

METHOD, STRUCTURE OF PAPER, AND THEORETICAL FRAMEWORK

The remaining portion of the paper discusses cycles of design-based research aimed at developing effective approaches for science teacher education. The methodology in this paper is consistent with aspects of design experiments (Brown, 1992) and self-study (LaBoskey, 2007). The outcomes of each intervention in my own elementary science methods class helped to clarify goals and point toward needed refinements in approaches. This information then guided the design and implementation of my subsequent efforts.

The first study discussed in this paper describes the outcomes of introducing preservice teachers to modeling and simulation tools. The results from this work led toward a second study involving the use of a science teaching and lesson-sequencing framework. My subsequent efforts involved helping preservice teachers critically analyze and effectively use curriculum materials. The outcomes of these three efforts, along with those of my colleagues who submitted papers for this issue, have led me toward theorizing appropriate goals for supporting well-started beginning teachers along a continuum of development as well as determining principles of effective elementary science teacher education.

This work makes use of several theoretical frameworks in understanding and supporting teacher learning in science teaching, primarily taking a socio-cognitive approach. I have focused on teacher learning as acquiring professional knowledge, practices, tools, vision, and disposition (Hammerness et al., 2005; Shulman, 1987). At the same time, this work has made use of socio-cultural perspectives involving teachers' enculturation into communities of practice, using the tools and discourses of those communities (e.g., reform-based science teaching, school-based science teaching, and so on; Putnam & Borko, 2000; Wenger, 1998). It is important to note that the frameworks used throughout the research have changed over time as the work has evolved. For example, the first and second studies made use of the cognitive framework of teacher knowledge as encompassing content knowledge, pedagogical content knowledge, and pedagogical knowledge (Shulman, 1987). Both studies focused on a particular dimension of pedagogical content knowledge—that of science teaching orientations or teacher knowledge and beliefs that guide a teacher's goals and methods for teaching science (Magnusson, Krajcik, & Borko, 1999). The first study also focused on preservice teachers' knowledge about science and technology. The second study focused on lesson-planning practices in science teaching using tools that can scaffold such practices. The final study makes use of the idea of tools such as frameworks, criteria, curriculum materials as mediating teacher-curriculum interactions (Remillard, 2005) and participation in communities of practice. The second and third studies also assume that such tools and their use with curriculum materials can be modeled, scaffolded, and faded (Brown, Collins, & Druguid, 1989) to help preservice teachers develop professional knowledge and practices.

Study 1: Modeling and Simulation Tools for Preservice Teachers

My prior work with middle school students who participated in modeling and inquiry practices while learning about force and motion using computer simulation models

(Schwarz & White, 2005) led me toward my early efforts to introduce modeling and simulation tools to preservice teachers (Schwarz, Meyer, & Sharma, 2007). Outcomes from my work in seventh-grade classrooms indicated that middle school students engaged in significant modeling-centered inquiry using technology and that they improved their understanding of science content, scientific inquiry, and the nature of scientific models. I wanted preservice teachers to learn about and use modeling tools to help them develop their understanding of modeling-centered scientific inquiry, learn about productive uses of technology tools for engaging children in classroom inquiry (Bruce & Levin, 1997), and develop a repertoire of software and other tools for teaching modeling-centered scientific inquiry. I theorized that learning about modeling and simulation tools could help advance preservice teachers' knowledge about science and provide them tools for addressing the problem of practice of engaging students in science.

Computer modeling and simulation tools are science-specific tools that represent data or phenomena in ways that can help predict and explain those phenomena. Educational versions of such tools in conjunction with reform-based science teaching can help foster subject matter knowledge as well as systems thinking (Feurzeig & Roberts, 1999; Mellar, Bliss, Boohan, Ogborn, & Tompsett, 1994). They can also enable learners to participate in scientific practices of data collection and analysis, as well as theory building and revision (Stewart et al., 2005; White & Frederiksen, 1998). In conducting this study, I argued that teachers should know about and have access to these important forms of tools for their future classrooms. Furthermore, I hypothesized that such tools could also serve as a vehicle for thinking deeply about scientific epistemology and pedagogy. In other words, learning about and using modeling tools might provide preservice teachers some leverage in understanding science and science learning as a practice involving constructing and revising scientific models by generating and evaluating evidence within a scientific community.

This intervention involved introducing, using, and helping preservice teachers learn about and engage with modeling and simulation software within my one-semester elementary science methods course. The intervention included three primary components: (1) use of two examples of computer simulation software (Starry Night™ and Riverdeep's ZAP!™) within science investigations about solar motion[2] and electricity in order to help preservice teachers see, experience, and reflect on how some specific examples of technology can be incorporated into science teaching; (2) discussions about technology and modeling tools to provide a rationale and framework for technology integration; and (3) investigations of one of five modeling or simulation tools in science and incorporation of those tools in science lesson plans in order to help preservice teachers envision how they might use such tools in their own science teaching. Those tools included ThinkerTools™ (force-and-motion: White & Frederiksen, 1998), Model-it™ (general relation-based: Spitulnik, Ktajcik, & Soloway, 1999), Archimedes & Beyond™ (matter: Smith, Snir, & Raz, 2002), Models of Matter™ (matter: Smith, Snir, & Grosslight, 1992), and MARS™ (matter: Raghavan & Glaser, 1995). These tools and others are included on a Web site designed for preservice teachers' use within the course (link on http://schwarz.wiki.educ.msu.edu/).

My colleagues and I used a variety of data sources such as pre- and posttests, videotapes of classes, journals, lesson plans, and interviews with 10 preservice teachers to determine what preservice teachers learned about educational software and how the intervention shaped their views of science pedagogy and their understanding of scientific epistemology. We analyzed pre-post differences, nature of software use in lesson plans, and themes related

[2] While Starry Night™ is typically used to view motion of nighttime objects in the sky, it also simulates the sun's daily motion across the sky during different times of the year—making it easier to observe patterns in solar motion and connect these to seasonal changes.

to epistemology and technology within journals and interviews. Note that a complete description of our methods is reported elsewhere (Schwarz et al., 2007), and a summary of outcomes from this study and others described in this paper are presented in Table 1.

Our analyses of these data pointed to several findings. First, the intervention expanded the majority of preservice teachers' understandings about the role of technology and the type of technology available. For example, one preservice teacher stated in her interview,

> 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 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 decide 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.

More interestingly, preservice teachers' 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—not the research-based modeling software that was somewhat unstable, sometimes looked old, and did not always provide scientific information. As one preservice teacher stated, "[In using the software], I thought there would be more—like a big bang like Woo! Little cartoons running around or something." Yet another expressed disappointment and frustration with the software by stating,

> I just expected . . . more . . . like, the computer will tell you what to do. You will get more directions. . . . So then 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 that 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 [of science]. . . . 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.

Analysis of preservice teachers' lesson plans and discussions around the tools 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. While roughly half of the technology lesson plans had students using the modeling software to investigate a particular phenomenon or to express ideas about a phenomenon (often for assessment), others designed lessons in which students used the software for practicing ideas or for observing the correct scientific answer, not as tools for theory building. For example, 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.

In addition to determining that preservice teachers had different expectations and visions of software use in the classroom and that they needed more support in developing their

TABLE 1
Comparison of the Goals and Outcomes for the Three Design-Based Research Studies

Study	Study Focus and Goals	Study Outcomes	Aspects of Approaches That Fostered Principled Reasoning About Problems of Practice and Approach Limitations
Study 1: Modeling and Simulation Tools for Science Teaching	Introduced, learned about, and planned lessons around computer modeling and simulation tools in elementary methods course to develop knowledge of modeling-centered inquiry in science, advance views about strong uses of technology for teaching, and obtain a repertoire of technology tools for teaching.	Expanded preservice teacher understanding about the role and type of technology tools available; Affordances of tools misaligned with preservice teacher goals; use of tools contributed to modest gains in preservice teacher knowledge about modeling-centered inquiry and its use in science teaching.	Variety of modeling and simulation tools advanced understanding of technology use in teaching. Needed more coherent and explicit framework to clarify modeling-centered inquiry and make it more applicable to perceived problems of practice. Needed to help preservice teachers reformulate views of effective science teaching to include modeling-centered inquiry.
Study 2: EIMA Instructional Framework for Science Teaching	Learned about and used a modeling-centered scientific inquiry instructional framework (EIMA) to develop knowledge about modeling-centered inquiry, refine views or orientations of effective science teaching, develop some initial lesson-planning practices, and a beginning repertoire of tools and lessons using modeling-centered inquiry.	Preservice teachers designed inquiry-based science lessons and changed their views of effective science teaching from didactic and discovery to guided inquiry.	Framework and instruction advanced preservice teacher views of effective teaching and advanced planning practices while developing a beginning repertoire of tools.

Continued

TABLE 1
Continued

Study	Study Focus and Goals	Study Outcomes	Aspects of Approaches That Fostered Principled Reasoning About Problems of Practice and Approach Limitations
			Coherent course focus on modeling-centered inquiry, a robust framework that addressed problems of practice, and opportunities to understand and apply framework promoted advances. Needed to help preservice teachers understand how to effectively incorporate models and modeling and practice analyzing curriculum materials.
Study 3: Elementary Teachers and Curriculum Materials	Used Project 2061 Evaluation Criteria and modeling-centered inquiry criteria to analyze and modify curriculum materials in order to help develop and refine views of effective science teaching, engage in curriculum materials analysis and modification practices, and build a repertoire of lessons for teaching.	Preservice teachers made modest gains in learning about and using the criteria in their curriculum material analysis and lesson plans, and made modest changes in their views of effective science teaching to address reform-based qualities. Preservice teachers had own criteria that did not match Project 2061 Criteria, and they did not find criteria or analysis useful or authentic.	Large number of criteria and frameworks diluted course emphasis; preservice teachers had difficulty accessing meanings behind the criteria; the criteria did not overlap with their own, and criteria use did not address their perceived problems of practice. Needed a coherent framework and vision of effective science teaching, opportunities to unpack and negotiate reform-based approaches that also address needs and goals of preservice teachers, and coordinate approach with field placement sites.

lesson-planning practices to engage students in scientific practices, we also found evidence that preservice teachers struggled to make sense of modeling-centered scientific inquiry. For example, they held vague notions of scientific models as “something that takes a broad idea and paints a picture for you of a difficult concept, or break something down into parts. It’s a way of helping understand something that might be a little more difficult” rather than a more specific notion of a scientific model as a representation that can help externalize aspects of theories which can then make those theories accessible and testable. Preservice teachers also held vague notions of scientific inquiry as “raising questions and search[ing] after them” as opposed to thinking of scientific inquiry as a process that also involves generating evidence that can be used to formulate and evaluate explanations and communicating those findings to others.

Finally, preservice teachers also had difficulty understanding how inquiry and modeling were related to one another or how the computer modeling tools could be used to help students learn about or participate in the practices of science. When asked during an interview about the similarities between science and model building, for example, rather than stating that science is an inquiry process that often involves model building, testing, and revising, one preservice teacher replied, “I don’t know. I guess it [science and model-building] 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.”

These results indicated that our approach in the course and the computer simulation and modeling tools were not a powerful enough leverage for preservice teachers to understand or engage their own students in inquiry and modeling scientific practices. Preservice teachers’ confusion around modeling and inquiry practices and their difficulties applying modeling-centered inquiry using technology tools indicated, among other aspects, the need for a more coherent framework that was more central to their teaching practice and could help them better understand or engage their own students in scientific practices. Foregrounding a framework that makes instructional features explicit could help clarify and structure scientific modeling and inquiry practices, reformulate preservice teachers’ ideas about the nature and pedagogy of science practices, and enable them to take advantage of the affordances of the computer modeling and simulation tools. I hypothesized that a framework might also help preservice teachers meet their own goals of engaging their students in science and building their repertoire of science lessons for organizing instruction.

Study 2: EIMA for Science Teaching

The outcomes from this first study indicating the need for a more coherent and explicit framing of modeling-centered inquiry led toward a second design-based research effort incorporating a modeling-centered inquiry instructional framework into the methods course (Schwarz & Gwekwerere, 2007). My goals for this effort entailed helping preservice teachers develop some professional knowledge about modeling-centered scientific inquiry and thereby refine their views of or orientations toward effective science teaching (Magnusson et al., 1999) to include reform-based approaches. It was also my goal to help preservice teachers develop some initial pedagogical skills for teaching modeling and inquiry practices and a beginning repertoire of tools and lessons for such an approach—thus addressing problems of practice related to engaging students in science and organizing instruction. I speculated that a framework around modeling-centered inquiry might serve as tool that could enable preservice teachers to advance or synthesize knowledge about how to teach science, guide their own pedagogical and planning practices, and apply core principles of reform-based science teaching. By instructional framework, I refer to a simplified representation of the process one might engage in and the content one might address while teaching science. Examples of other instructional frameworks and models include the BSCS (Biological Science Curriculum Study) five E's approach (Bybee, 1997) as well as others (Zembal-Saul, 2009, this issue). Prior research has indicated that instructional frameworks can support coherent learning experiences that can help students build new understandings over time and improve teachers' use of inquiry (Abraham, 1998; NRC, 2000).

Our guided inquiry and modeling framework, EIMA (engage–investigate–model–apply), was adapted from the BSCS five E's inquiry model (Bybee, 1997) and incorporates inquiry and modeling components to further emphasize, clarify, and incorporate the scientific practice of modeling-centered scientific inquiry. EIMA stands for (1) **e**ngaging students in the topic and eliciting their prior ideas; (2) helping students **i**nvestigate the topic, phenomena, or ideas, with high priority for data collection and analysis of those data into patterns; (3) helping students create **m**odels (generalized representations that account for causal aspects of the phenomena or represent patterns in the phenomena) or explanations (specific claims about the answer to the question sometimes generated from a model—with reasoning behind that claim), and comparing and reconciling those models and explanations with those from the scientific community; and (4) asking students to **a**pply those models or explanations to novel situations. Use of the EIMA framework also emphasizes creating a community of learners and using the tools of science.

The intervention using the instructional framework took place in several phases of instruction within the methods course. First, preservice teachers read, reflected on, and discussed readings and concepts about science (e.g., what science is, why students should learn about it), learning (e.g., how students learn science and what they are expected to learn as indicated by the standards), and approaches of teaching science (e.g., didactic, discovery, conceptual change, communities of learners) within small group and large-class discussion. Preservice teachers then constructed their own version of a teaching or lesson-sequencing tool before being introduced to the EIMA framework as a tool for teaching and constructing lesson plans. For example, one group of preservice teachers created the general instructional sequence of "eliciting students' prior ideas, engaging students in hands-on/minds-on activities, engaging students in exploring, and reflecting on their ideas." We then introduced EIMA as a framework similar to their own, but one more elaborated for teaching and constructing lessons plans in science. While introducing the framework, we also provided them with a six-page description of EIMA that unpacked and provided a rationale for each framework dimension and included examples of teacher and student activities within each dimension. We note that while the "model" component of EIMA was described in detail within his document, the instructor did not explicitly teach preservice teachers about the nature and role of models. While teaching the course, the course instructor focused more on helping preservice teachers understand the general nature scientific inquiry rather than modeling-centered inquiry.

The intervention around the EIMA framework included several other components. Teachers experienced model-centered science inquiry activities (using EIMA) within demonstration teaching units on light and electricity. They also worked in small groups to create two sets of lesson plans—one of which they taught in elementary classroom field placement sites. In these lesson plans, they were encouraged to use EIMA, but not required to do so.

We analyzed classroom artifacts, lesson plans, transcripts of peer interviews, pre-post tests, and reflective journals to determine whether the preservice teachers used EIMA, whether they learned how to plan modeling-centered guided inquiry lesson plans, and whether the framework and other components of the methods instruction changed their science teaching orientations. A more complete description of the analysis can be found in Schwarz and Gwekwerere (2007).

Patterns in results indicated that the majority of preservice teachers used and adapted EIMA for their science planning and teaching (Schwarz & Gwekwerere, 2007). While nearly all preservice teachers specifically followed EIMA in one set of lesson plans for the course 3 weeks before the end of the semester (in which they were asked to address the various components of the framework and were scaffolded by the instructor in its application), the majority of preservice teachers adapted EIMA within the final, more open-ended lesson plans in which they were asked to choose and address several dimensions of the framework. Analysis of these lesson plans indicates that 17 of the 24 preservice teachers either used EIMA as the framework for their lesson or adapted EIMA to other guided inquiry frameworks such as "engage, investigate, and discuss explanations." Again, we note that while many of these lesson plans were explanation-centered rather than modeling-centered versions of EIMA, they were nonetheless productive inquiry lessons that addressed reform-oriented science teaching.

For example, one pair of preservice teachers wrote a final lesson plan on sinking and floating for kindergarten students that adapted EIMA to an explanation-centered inquiry approach. Their lesson plan involved having the teacher ask students to predict which objects would sink or float and brainstorm ideas (engage). The teacher and students tested each item in a tub of water and compared their predictions with results and shared (investigate). After some discussion about initial patterns, the students further investigated sinking and floating of different objects at stations (investigate). The teacher asked probing questions to guide them in their investigations. The students then discussed their findings and had a teacher-facilitated science talk with teacher direction about why certain items were able to float (explain).

We found similar patterns in preservice teachers' use and adaptation of the EIMA framework in their pre- and postassessment lesson plans. In the pretest, the majority of preservice teachers (76%) began the semester by designing lessons that were primarily activity driven or didactic in nature compared to 8% who designed inquiry or partial inquiry-based lessons. At the end of the semester, half of the lessons (50%) were coded as guided inquiry or inquiry-based, whereas 42% of the lessons were coded as didactic or activity driven in nature. For example, one preservice teacher wrote an activity-driven and didactic lesson on her pretest that involved students observing physical models of molecular motion and then drawing a picture or using manipulatives to show the model. This lesson was coded as both activity driven and didactic as it involved the teacher presenting some information and students participating in "hands-on" activities used for verification or discovery of the concepts. On her posttest, the preservice teacher designed a modeling-centered inquiry lesson plan that involved that teacher posing a question about why we have seasons, having students construct an initial model with globes to answer why we have seasons, conducting research on why we have seasons, having a science talk about why we have seasons, and revisit their initial model to determine whether it could accurately explain why we have seasons. We coded this posttest as modeling-centered inquiry in the sense that there was a question posed (engage), research to determine how the seasons occur (investigate), and the generation of causal explanations using models (model/explain).

With respect to scientific modeling, we found that, while preservice teachers further incorporated models within their lessons plans at the end of the semester, they did so in some unanticipated ways. For example, while they asked students to construct or use models that embodied patterns in data or causal explanations, some preservice teachers asked students to construct models of typical objects or phenomena. Examples of such models include a model cloud when studying clouds and weather or a model lever or wheel and axle when studying simple machines. Analysis of preservice teacher journals indicates that while some preservice teachers made progress in better understanding the nature of scientific models and how to incorporate them into their lesson plans, others did not.

Analysis of self-reported posttest data and peer interviews at the end of the course confirmed the finding that preservice teachers moved away from didactic and discovery orientations and toward inquiry, guided inquiry, and other reform-based orientations of science teaching. For example, one preservice teacher who thought that her teaching orientation had changed stated on her posttest,

> Coming into this class, I felt science was more of basic subject. You have your facts, you present them, understand them and that is it. Now, I can see how important it is to investigate the problems, I can see that providing explanations is necessary.

Another whose orientation changed stated,

> I used to put a huge focus on "hands on" as I enjoy doing this aspect of science. I now see there needs to be more than just activities, and inquiry includes investigating, drawing conclusions, and assessing the validity [of those conclusions]—all important parts of science learning.

In summary, this approach using the instructional framework served to advance preservice teachers' orientations of teaching science toward guided inquiry, helped them develop their knowledge and lesson-planning practices around guided inquiry (though not effectively for scientific modeling), and it helped them develop a beginning repertoire for science teaching. What aspects of this approach might have led to such changes? Analysis of these and other sources of data such as case studies of preservice teacher journals (Schwarz & Gwekwerere, 2007) led us to hypothesize that EIMA provided a useful tool for planning lessons, regardless of science teaching orientations and in negotiating lessons with peers. We also found some evidence that ideas from the readings on science, learning, and teaching seemed to have impacted preservice teachers' orientations and skills as well as the class' ideas about good science teaching. Furthermore, evidence pointed toward the importance of having scaffolded experiences learning about and teaching using this approach in specific content areas.

Nonetheless, there were limitations to the approach. The intervention and experiences spanned one semester, so preservice teachers had few experiences critiquing or modifying lesson plans to decide what is and is not modeling-centered scientific inquiry and how they might teach other science content areas. Furthermore, while preservice teachers made strong advances in understanding and developing lesson-planning practices around scientific inquiry, they made fewer advances in incorporating models and modeling into their lessons. At the end of this study, we theorized that preservice teachers needed additional opportunities to work through ideas and strategies for how to incorporate scientific models and modeling effectively in science teaching contexts. We also determined that preservice teachers needed practice analyzing curriculum materials and modifying them to address important components of modeling-centered inquiry as well as strategies to determine when one might want to abandon or modify a modeling-centered inquiry approaches within the classroom.

Study 3: Elementary Teachers and Curriculum Materials

In the next phase of my work, I had the opportunity to explore how to support preservice teachers in analyzing and modifying curriculum materials in preparing for their future teaching practices (Davis & Smithey, 2009, this issue; Schwarz et al., 2008). While this third study was not a continuation of the second, it nonetheless provided a context in which to explore promising approaches for effective teacher education that could add to my prior findings. Preparing preservice teachers to effectively use curriculum materials is an important issue (Davis, 2006) as curriculum materials play a significant role in both shaping elementary science instruction and guiding beginning teachers (Ball & Feiman-Nemser, 1988; Grossman & Thompson, 2004; Kauffman, Johnson, Kardos, Lui, & Peske, 2002; Mulholland & Wallace, 2005). Unfortunately, many of the current materials are of poor quality (Kesidou & Roseman, 2002; Stern & Roseman, 2004). In considering how to help preservice teachers learn how to teach science effectively and having the opportunity to study how to help preservice teachers learn to use curriculum materials, I theorized that giving preservice teachers opportunities to work with science curriculum materials could be useful for helping them refine their views of effective science teaching and potentially align their own views with those of reform-based practices as well as develop their critical analysis practices and build their repertoire of lessons for teaching.

As a result, I worked with several teacher educators to investigate how to help preservice teachers analyze and modify curriculum materials using the American Association for the Advancement of Science Project 2061 Instructional Analysis Criteria. The Project 2061 Criteria can be used to evaluate how well materials address specified learning goals and support teachers and students in achieving those learning goals (Kesidou & Roseman, 2002; Stern & Roseman, 2004). The Project 2061 Criteria favor materials that establish a sense of purpose, engage students with scientific phenomena, present students with scientific ideas, provide students with opportunities to use scientific ideas and apply them to new situations, provide teachers with effective assessments of student progress, and provide enhanced learning environments for all students.

This study took place in three elementary science methods sections including my own. In each section of the methods course, the instructor used the criteria as a tool to help the preservice teacher analyze materials to identify strengths and weaknesses of materials and to make modifications that take advantage of the strengths while addressing the weaknesses. In my section of the course, for example, I used the criteria and the EIMA instructional model previously discussed (Schwarz & Gwekwerere, 2007) to support and specify important dimensions of teaching focusing on modeling-centered scientific inquiry. For example, my methods section used some Project 2061 Criteria as well as my own innovated modeling-centered inquiry criteria that emphasized providing an opportunity to engage with relevant phenomena, to analyze data into patterns, and to create and compare explanation and models derived from those patterns. I note that adding an emphasis on the evaluation criteria and curriculum materials analysis shifted the course from a focus on modeling-centered inquiry and frameworks toward more general principles of effective science teaching found in the Project 2061 Criteria such as eliciting students' ideas, applying scientific ideas to new contexts, and engaging in continuous assessment.

Preservice teachers within my section used the criteria to critique and modify three unit plans, including two demonstration units on electricity and force and motion, and their own unit plan completed at the end of the course. For each unit, preservice teachers worked in small groups to discuss whether the materials met the criteria and how they might modify the materials to better meet the criteria. The meanings of the criteria were not discussed individually, but rather used within a sample analysis I provided for both demonstration units and negotiated among preservice teachers when they shared their unit analysis with one another in class.

My goal in using the Project 2061 and modeling-centered inquiry criteria was to aid preservice teachers in becoming more effective elementary science teachers by understanding characteristics of good science teaching and being able to identify curriculum materials that supported these characteristics. Furthermore, I also wanted preservice teachers to use these tools for identifying important features of modeling-centered inquiry in lessons or units such as thinking about whether the materials provided adequate opportunities for analyzing patterns in the data or opportunities for students to construct and compare explanations and models with the patterns. I hoped that such answers might enable them to modify the lessons or units to meet those criteria by, for example, engaging children in analyzing patterns in data and constructing and compare models and explanations.

Analysis of pre-post assessments, classroom artifacts (including unit analysis forms), classroom dialogue, and postcourse interviews indicated mixed effectiveness of this approach for advancing their curriculum materials analysis and lesson-planning practices as well as their views of effective science teaching (Schwarz et al., 2008). In particular, we found that preservice teachers had some success in learning and using the criteria (and the ideas behind those criteria) in their lesson analysis and planning, but the gains in using those criteria for analysis and lesson planning were disappointing.

Preservice teachers were only partly able to identify features of modeling-centered inquiry and modify lessons to address modeling-centered inquiry. For example, preservice teachers from my section of the course increasingly attended to and accurately applied the criteria of engaging students in relevant phenomena and providing opportunities for analyzing data into patterns in their analysis and design of lesson plans. As an example, by the end of the semester, the majority of preservice teachers accurately used the criteria for "patterns in data" by making statements in their unit analysis sheets such as

> [our unit meets the 'analyzing data' criterion because] after the students have had the opportunity to reflect upon what they have eaten for dinner and create a food chain, the students are asked to look at commonalities across the food chains of peers. They should . . . notice that all food chains begin with the sun providing energy for a plant and that they are at the top of the food chain as the primary consumer.

Preservice teachers also spontaneously raised the issues of data collection and analysis in their evaluation of curriculum materials in their formal evaluations and their small group discussions.

Unfortunately, preservice teacher postassessment lesson plan sequences did not significantly attend to the majority of other criteria including other important dimensions of modeling-centered inquiry such as addressing the learning goal and providing opportunities to create explanations or models from patterns and compare those explanations and models with those of others and from the scientific community. Analysis of their use of these two criteria within their own unit plan evaluation indicated that they did not accurately interpret the criteria—sometimes interpreting learning goals as topic area, and patterns in data or particular phenomena as explanations and models. Furthermore, preservice teachers did not adequately address these dimensions in their own lesson sequences. It appeared that while they were interested in having their students collect and analyze data, those data were not linked to the construction and evaluation of explanations and models. Furthermore, their lesson plans did not provide adequate opportunities for application and practice using explanations and models.

To determine more information about the preservice teachers' lesson-planning practices, we analyzed the overall nature of preservice teachers' lesson sequences from our curriculum materials analysis and sequencing pre-post assessment. Results indicated that there was a modest increase in lesson sequences that involved inquiry and conceptual change (3/10 in the pretest to 5/10 in the posttest). Inquiry lesson sequences included investigation activities such as collecting data, making predictions, analyzing data, talking about findings, and explanations and conceptual change lessons included preassessment, teacher explanation, and students' experiments to address students' misconceptions. There was also a slight decrease in didactic instruction with hands-on activities from pre- to postassessment (5/10 in the pretest compared to 1/10 in the posttest) or instruction involving a teacher explanation followed by student activities. Nonetheless, there was also an increase in discovery-based lessons (1/10 in the pretest to 4/10 in the posttest) or lessons that involved student exploration of the phenomena with no explanation.

Did this approach using the criteria and analyzing curriculum materials help preservice teachers work through and develop their knowledge and views of teaching? Again, the outcomes from the approach were mixed. Survey data from my section of the course about their teaching orientation (self-described) indicated that their focus on activity-driven science teaching decreased throughout the semester (17 of 24 or 71% in the pretest compared to 11 of 24 or 46% in the posttest) and they increasingly focused on conceptual change (1 of 24 or 4% in the pretest compared to 9 of 24 or 38% in the posttest) and guided inquiry (9 of 24 or 38% in the pretest compared to 15 of 24 or 63% in the posttest). Nonetheless, when preservice teachers were asked about the purposes and goals for teaching science, the largest change in their pre-post statements was an increased focus on getting students excited about science (8 of 24 or 33% in the pretest compared to 14 of 24 or 58% in the posttest). Their focus on promoting students' understanding decreased slightly (from 9 or 24 in the pretest compared to 8 of 24 in the posttest). To illustrate the range and type of responses, see Table 2 for a sample of two preservice teachers' responses to several survey questions. Mandy's responses indicate some change in her views about science teaching and Lydia's indicate few changes. In each of these responses, preservice teachers attended to hands-on activities, authentic activities, ensuring that students have fun, and assessment. In the posttest, Mandy also attended to the idea of inquiry, EIMA, communities of learners, and science talks.

Analysis of the overall data in the instructional trial of these three methods sections indicated (as can be seen in Table 2) that preservice teachers had their own criteria for evaluating the strengths and weaknesses of lessons and modifying the lessons, and those criteria overlapped very little with those introduced in the course (Schwarz et al., 2008). Analysis of artifacts from all sections indicated that preservice teachers broadly focused on practical and affective goals such as making science fun, relating science to everyday life, making science applicable, and doing hands-on experiments.

Finally, interview data suggested that the preservice teachers did not find the criteria or the analysis and modification of the units using the criteria useful or authentic. As one preservice teacher from my section stated,

> I felt like the criteria that we were supposed to be, you know, evaluating with just didn't enhance anything that we were doing. . . . I think it would really help if the criteria were something implemented by the CT's [cooperating teachers]. So that you could see how it would be useful. Because it did seem like there was a huge disconnect between what our CT does and the things that we were doing in class.

Later, she stated, "I've been in the classroom . . . myself [and] I would have thought, you know, that you will never have time to look at all these things when you are planning the lesson."

My instructional approach using Project 2061 Criteria and modeling-centered inquiry criteria for preservice teachers' curriculum materials analysis and modification had limited impact in helping the preservice teachers use reform-based science teaching approaches in

TABLE 2
Contrasting Sample Responses From Preservice Teacher Survey in Study 3

Mandy's Responses	Lydia's Responses
Science teaching orientation (self-described)	
Pretest: Discovery Posttest: Conceptual Change and Guided Inquiry	Pretest: Activity driven Posttest: Activity driven
Describe what you think is good or effective science teaching.	
Pre: "Lots of hands-on activities, group work"	Pre: "I feel that the classroom should involve lots of hands-on experiences with room for questions and peer discuss."
Post: "Inquiry—students engaged in investigations, science talks, EIMA"	Post: "I'm a visual learner so I feel that videos (interactive), presentations, hands-on activities and group discussions are a great way to teach science concepts."
What are some of your purposes and goals for teaching science?	
Pre: "To help students become curious about the world and find ways to answer their questions. To encourage a joy for science."	Pre: "I hope that all of my students take something valuable from my lessons. I hope to add (create) many authentic lessons (if possible)."
Post: "*Help students learn how to find own answers to questions *use tools *community of learners *everyday connections"	Post: "I hope that my science teaching will be fun, interactive, unique, and informative to my students. I hope to incorporate authentic activities wherever possible."
Write down what you have learned (post).	
"I have learned about science inquiry. It has really changed the way I thought about science teaching. I noticed the change when I was planning my unit . . . . I was having them do more science inquiry, community of learners, modified for different types of students, various types of assessments (pre-assessment, formative, commutative [sic]). I also learned about EIMA, science talks."	"*I've learned about different ways to pre-access students' prior knowledge as well as different activities to teach them about certain topics. *I've also learned about many different resources to get use science tools and info [sic]."

their teaching practices (analysis and modification of curriculum materials as well as lesson planning) and develop their reform-based science teaching knowledge and views. There are several likely reasons for this outcome. First, the large number of criteria and other frameworks introduced in the course was confusing for preservice teachers and diluted the course emphasis. Second, the criteria and frameworks were not well integrated with one another, leaving preservice teachers without a way to understand how they fit together into a coherent image of effective science teaching. We note that the instructional frameworks used in all three sections played a much more prominent role impacting preservice teacher thinking and lesson planning than did the isolated criteria. This was likely due to the fact that the instructional frameworks could help preservice teachers construct and sequence lessons rather than just critique them. They also provided more coherent images of effective science instruction.

Third, preservice teachers sometimes had difficulty accessing the meanings behind the criteria. Many of the ideas behind the criteria as well as the language of the criteria were unfamiliar to preservice teachers. For example, some of the terms such as "application and practice" were not well aligned with preservice teachers' vernacular use of those terms who considered "application" as ideas that connected to the real world and "practice" as interaction with materials. Furthermore, the criteria did not overlap with preservice teachers' own criteria—making the meanings of the criteria more difficult to access, as well as making the practices using those criteria less relevant for meeting preservice teachers' own goals.

Fourth, preservice teachers did not perceive the process using the criteria to analyze and modify curriculum materials as central or relevant for their perceived future teaching practices. This was likely due in part to their perception of the inconsistency between what was advocated in the methods course and what they observed in their classroom placements. It was also exacerbated by the challenges accessing the meaning of the criteria and the lack of congruence between the criteria and their own goals. As a result, preservice teachers showed indifference and sometimes resistance to these curriculum materials analysis and modification practices that may have seemed inauthentic and destabilizing.

REVISED ETCM (ELEMENTARY TEACHERS AND CURRICULUM MATERIALS) APPROACH

Outcomes from the analysis of the instructional trials using the criteria pointed us in promising new directions. For example, rather than using the criteria as individual components, we constructed a new streamlined and coherent instructional framework that incorporates the elements of the criteria (Gunckel, Bae, & Smith, 2007). The instructional framework is similar to EIMA, but incorporates aspects related to curriculum materials analysis and modification. It is designed to help preservice teachers construct a reform-based view of instruction and to help them analyze and modify materials in a manner consistent with that view. Given the challenges of accessibility associated with the language of the criteria and the reform-based ideas, we have also provided preservice teachers multiple opportunities to negotiate the meaning of the reform-based approaches including the instructional framework within such activities as our curriculum materials analysis tasks. Furthermore, efforts were made to coordinate approaches with the cooperating teachers in classroom placement sites.

This coordinated approach has been significantly more effective than our prior approach at advancing preservice teachers' views of effective science teaching as well as their lesson-planning practices. Analysis of data indicated that the instructional framework was effective in supporting preservice teachers in rethinking effective science teaching as well as designing inquiry and application lesson plans around specific learning goals (Gunckel et al., 2007). Analysis of the curriculum materials analysis tasks indicates that the task functions as a boundary spanning activity, creating a space that enables preservice teachers to work with their own goals and Discourses[3] (Gee, 1990) as well as reform-based Discourses (Covitt, Schwarz, Mikeska, & Bae, 2008). Finally, the meetings between the cooperative teachers and the methods instructors appeared to help make the practice of curriculum

[3] A Discourse is "a socially accepted association among ways of using language, of thinking, feeling, believing, valuing, and of acting that can be used to identify oneself as a member of a socially meaningful group or 'social network,' or to signal (that one is playing) a socially meaningful role" (Gee, 1990, p. 143).

materials analysis and modification more visible to preservice teachers and to help align the practices in the methods courses with those from the K-8 classrooms.

While these findings and new approaches have not specifically focused on modeling-based inquiry as a target teaching practice, they lend insight into effective approaches for how to advance preservice teachers' knowledge and practices that can be transferred to fostering modeling-based inquiry approaches. For example, this recent study lends additional support to my earlier work with EIMA for using an instructional framework to develop preservice teachers' view of effective science teaching and their teaching practices. Using our instructional frameworks in the methods course seems particularly effective for helping preservice teachers design lessons that engage learners in experiences and investigations before explanations as well as develop a view of science teaching that is generally more nuanced than pure discovery or didactic approaches. The outcomes from this study also highlight the differences between preservice teacher goals and perceived problems of practice compared to reform-based goals and emphases. They also point to the need to negotiate and unpack the reform-based emphases in a way that also serves the needs and goals of the preservice teachers as well as providing meaningful context to work through and apply the new approaches. This is undoubtedly true for a modeling-centered inquiry approach that depends on an understanding and focus on scientific inquiry and learners in the classroom community while at the same time a focus on constructing and revising scientific models. Finally, the outcomes also highlight the role of preservice teachers' membership in multiple communities of practices with different and sometimes oppositional views about effective science teaching as well as preservice teachers' status in those communities (and therefore, their perceived agency for changing curriculum, norms, and enacting reform-based science instruction). The implications of this participation and status within communities foregrounds some additional challenges preservice teachers face both working through their notions of modeling-centered inquiry as well as enacting such an approach in the classroom.

SUMMARY AND FUTURE DIRECTIONS

The evolution of my work has followed a trajectory that began with a focus on helping preservice teachers use computer modeling and simulation tools for engaging in scientific practices to approaches, experiences, and tools that help preservice teachers develop their teaching practices that align with scientific practices and tools. Similarly, my goals for preservice teacher professional knowledge and practices have shifted from helping them know more about the nature of science through scientific practices to helping them refine their knowledge and views of effective science teaching, develop effective lesson-planning and curriculum materials practices for fostering productive science learning communities, and gain a reflective or critical disposition in which to continue learning through teaching. My most recent work has led me toward considering how to help preservice teachers explicitly negotiate their own goals with those of reform-based science as well as how to help them effectively navigate their roles in various communities of practice. Furthermore, I continue to work to determine how to more prominently integrate the learner in the preservice teacher practices—and to determine where along a teacher's learning trajectory and placement experience is the most effective place to incorporate learner's perspectives and repertoires of practice. As the preservice teacher moves her or his work into the classroom, it is essential to move the learners to the focal point of the conversation while keeping science learning goals central to that conversation.

Effectively educating preservice elementary teachers is a design challenge (Brown, 1992). While one aspect of an approach is emphasized and foregrounded, another important aspect may be unintentionally backgrounded or misconstrued. As with others who have struggled with these issues (Davis & Smithey, 2009, this issue; Zembal-Saul, 2009, this issue), we wonder what combination of approaches or emphases are likely to produce positive effects for most preservice teachers. In other words, as stated earlier, how can these various approaches and others discussed in the literature be synthesized to create effective approaches for elementary preservice science teacher education?

Patterns in results from my own work as well as others have led me toward speculating about principles of potentially successful approaches for advancing elementary teacher knowledge and practices that address core problems of practice. One of these principles is having a coherent learning goal for a methods course that reflects the underlying nature of the content area (Darling-Hammond & Bransford, 2006). With respect to my work, this has meant a coherent approach on modeling-centered scientific inquiry within a productive learning community. An important aspect of this principle is enhancing preservice teachers' knowledge of science and helping them reformulate their views of effective science teaching by working through some of their objectives of teaching. Study 2 was the most coherent and systematic approach around this learning goal and the one most targeted at addressing preservice teachers views of science. Study 2 also had the largest impact on advancing preservice teachers' knowledge and practices.

Second, preservice teachers need robust tools and opportunities to unpack and apply these tools to engage in reform-based teaching. Tools, such as high quality science curriculum materials, instructional models or frameworks, and experiences such as curriculum materials analysis activities can provide access to reform-based goals and practices. Preservice teachers also need opportunities to unpack and apply these new approaches in multiple contexts, including K-12 classrooms to help them understand the meanings behind the tools and to make sense of them in applying to authentic problems of practice such as organizing instruction or developing a beginning repertoire of lessons. Studies 2 and 3 were the most active in introducing and enabling preservice teachers to unpack tools, though the instructional framework in Study 2 was most successful—in part because the framework was coherent and concise, so preservice teachers had more opportunities to unpack and apply framework components.

Finally, preservice teachers appeared to have advanced their knowledge and practices most within the approaches that addressed their perceived problems of practice. In particular, approaches and tools were more successful when they provided a bridge between reform-based goals and preservice teachers' own goals and practices (Covitt et al., 2008; Schwarz et al., 2008) around authentic problems of practice such as engaging learners in science and organizing instruction. Study 3 indicated that there was not much advancement in knowledge and practice when the approach did not align with preservice teachers' sense of authentic practice, and also points toward the importance of helping preservice teachers navigate their participation in multiple communities of practice with conflicting emphases and views of effective teaching.

Others within this paper set have followed these general principles—though the specific nature of their efforts, and the relative emphasis of particular aspects (such as foregrounding student ideas), has differed from my own. In particular, Zembal-Saul's approach focuses on the scientific practice of argumentation, on frameworks and tools that enable this practice, and on the learners engaged in this argumentation (Zembal-Saul, 2009, this issue). Furthermore, Zembal-Saul has worked toward obtaining a coherent approach across multiple communities of practice such as the methods course, the science courses, and the field experience. The approach has been successful at addressing problems of practice and has been highly effective at advancing teacher learning. Davis and Smithey (2009, this issue) address a set of foci around scientific inquiry, student ideas, and curriculum materials in their methods course. In this way, Davis and Smithey focus on a critical aspect of the science as well as the learners and the tools in which much of this enacted instruction is dependent. Not only does this approach address core problems of practice, but the authors have shown that preservice teachers can be supported to successfully engage in inquiry-oriented science teaching, principled analysis of curriculum materials, and purposeful adaptation of curriculum materials.

In addition to these ideas for designing effective approaches for elementary preservice teachers, there are other important and innovative approaches that need to be considered in thinking about effective methods for elementary preservice science teaching. In particular, preservice teachers need to better understand and develop culturally responsive teaching practices that draw on their diverse students' Discourses, funds of knowledge, and repertoires of practice (Calabrese-Barton, Gunckel, Covitt, & McLaughlin, 2007; LaVan, 2006; Moore, 2008). Furthermore, preservice teachers can also begin learning how to be reflective practitioners by conducting inquiry on their own teaching (van Zee, 2007).

In considering all of these research-based frameworks and theoretical approaches, which may have largest productive impact for which preservice teachers and in what manner? Those previously mentioned have shown productive outcomes and potential promise. Nonetheless, we need additional information from beginning elementary teachers from multiple communities in a variety of schools settings to expand and refine such approaches. One way of testing such approaches is to conduct research to develop elementary teacher learning progressions and trajectories along with common assessment methods. It is important to know how preservice teachers' knowledge and practices are refined and evolve in the beginning of their careers. One goal of such a progression would be to determine appropriate intermediate levels of expertise at various stages of development. A progression could also help determine effective supports and experiences that might help teachers achieve a particular level of expertise and effectively participate within a community of practice thus refining teacher preparation approaches and programs.

Given that there are new and challenging goals for what it now means to be proficient in science learning and teaching (NRC, 2007), we continue to work toward understanding and advancing ways for helping preservice elementary teachers become well-started beginners in learning how to teach science.

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