Learning to Teach Science as Inquiry in the Rough and Tumble of Practice

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Abstract: This study examined the knowledge, beliefs and efforts of five prospective teachers to enact teaching science as inquiry, over the course of a one-year high school fieldwork experience. Data sources included interviews, field notes, and artifacts, as these prospective teachers engaged in learning how to teach science. Research questions included 1) What were these prospective teachers' beliefs of teaching science? 2) To what extent did these prospective teachers articulate understandings of teaching science as inquiry? 3) In what ways, if any, did these prospective teachers endeavor to teach science as inquiry in their classrooms? 4) In what ways did the mentor teachers' views of teaching science appear to support or constrain these prospective teachers' intentions and abilities to teach science as inquiry? Despite support from a professional development school setting, the Interns' teaching strategies represented an entire spectrum of practice—from traditional, lecture-driven lessons, to innovative, open, full-inquiry projects. Evidence suggests one of the critical factors influencing a prospective teacher's intentions and abilities to teach science as inquiry, is the teacher's complex set of personal beliefs about teaching and of science. This paper explores the methodological issues in examining teachers' beliefs and knowledge in actual classroom practice. © 2007 Wiley Periodicals, Inc. J Res Sci Teach 44: 613–642, 2007

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The Problem

A decade has passed since the publication of national science education reform documents (i.e., National Research Council, 1996), advocating that science teachers engage students in doing and thinking about inquiry, and renewing an emphasis on teaching about the nature of science. Yet, it is clear that we are far from attaining our nationally stated goal of a shifting emphasis towards more inquiry-centered K-12 classrooms. It appears that all in the K-12 science teaching community do not embrace these recommendations. The state of affairs is that many teachers appear to have difficulty creating classroom environments that are inquiry-based, and that support their students in developing informed views of scientific inquiry and the nature of science (Chiapetta & Adams, 2000; Lederman, 1992; Marx et al., 1994; Minstrell & van Zee, 2000).

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The images of teaching science as inquiry in the reform documents (National Science Education Standards (NSES)) describe a range of instructional approaches, from open inquiry, in which students take the lead in identifying the problem, generating questions, designing investigations, making and recording observations, interpreting data, creating explanations, and developing models and arguments—to more structured inquiry, in which teachers determine the questions and specific procedures of the investigation (NRC, 1996, 2000). One issue with the NSES is that "the reader is left to create his or her own images of what constitutes this form of teaching" (Anderson, 2002, p3). Science inquiry in the classroom takes on different forms; and researchers, teachers, and teacher educators all may have very different views.

What does the author mean by inquiry in a science classroom, and why is it important? The NSES describe a vision that students in K-12 science classrooms develop abilities *to do* scientific inquiry, gain understandings *about* scientific inquiry, and that teachers facilitate students in acquiring deep understanding of science concepts *through* inquiry approaches (NRC, 1996). In this paper, the author consolidates these three aspects of inquiry (*to do, about*, and *through*) into a view of *teaching science as inquiry.* Important to this view of teaching science are the following student outcomes: appreciating the diverse ways in which scientists conduct their work; understanding the power of observations; knowledge of and ability to ask testable questions, make hypotheses; use various forms of data to search for patterns, confirm or reject hypotheses; construct and defend a model or argument; consider alternate explanations, and gain an understanding of the tentativeness of science, including the human aspects of science, such as subjectivity and societal influences. To enact teaching science as inquiry requires that teachers develop approaches that situate learning in authentic problems, model actions of scientists to guide and facilitate students in making sense of data, and support students in developing their personal understandings of science concepts (Crawford, 2000). The complexity of teaching science as inquiry in a K-12 school setting, and the demands on a teacher to take on a myriad of roles, may be important reasons why this kind of teaching is so rare (Crawford, 2000).

The challenge for novice teachers to integrate aspects of teaching science as inquiry into their planning and instruction is a daunting one. Yet, there is some evidence that it is not only possible, but also realistic to expect at least some prospective teachers to design and carry out this kind of reformed-based instruction (Crawford, 1999). On the one hand prospective teachers are capable of articulating an emerging knowledge of teaching science as inquiry, and they may espouse philosophies aligned with this kind of pedagogy (Crawford & Lunetta, 2002; Windschitl, 2003). On the other hand, novice teachers may be incapable of, unwilling to, or simply unable to enact teaching science as inquiry in their actual classrooms (McGinnis, Parker, & Graeber, 2004; Newman et al., 2004). A study of five beginning science and mathematics teachers revealed that an important influence on novice teachers' abilities to enact reformed-based instruction relates to their perceptions of a supportive or a non-supportive school culture—provided by the principal, students, parents, and other personnel (McGinnis et al., 2004). The complex interactions of various factors—conflicting views of school-based cooperating teachers, school context, student population, subject matter, university teacher education requirements, parental pressures, high-stakes testing, self-confidence, and the nature of prior authentic scientific research experiences—all may deflect a teacher's success in teaching science as inquiry. Research does not provide a clear picture of just how difficult it is to teach science as inquiry (Anderson, 2002). It is increasingly apparent that significant dilemmas exist in learning how to enact teaching science as inquiry, and that these are important to study (Anderson, 2002; Flick, 1997; Newman et al., 2004; Roth, McGinn, & Bowen, 1998; Windschitl, 2003). Prospective secondary science teachers' beliefs and knowledge of teaching science as inquiry, juxtaposed against the realities of what happens in practice, are the foci of this paper.

Overview of the Study

This study examines the beliefs and knowledge, intentions, and practice of five prospective high school science teachers, as they learned to teach science. Additionally, the author addresses the methodological issues involved in the examination of teachers' knowledge and beliefs in the rough and tumble of practice. During the last several years our research team studied prospective and practicing teachers' knowledge and beliefs and abilities to carry out the practice of teaching science as inquiry, in the context of an evolving high school–university partnership. In a series of studies the team examined the voices of prospective teachers and practicing teachers, as they articulated ideas, beliefs, and intentions of teaching science as inquiry (Crawford & Kreamer, 2002, 2003, 2004; Crawford, Kreamer, & Cullin, 2003; Guven & Crawford, 2004; Kreamer, 2003).

The setting for this study was a newly developed secondary Science Professional Development School [SPDS] (The Holmes Group, 1990). During the development phase of the SPDS the initiators provided mental spaces, by allowing each person from the school and university to articulate their personal philosophies of science teacher education, experiences and fears, and visions for the university–school partnership. Fourteen school science faculty and one university faculty member volunteered to meet and express their personal philosophies. Team members developed a Mission Statement, Goals, and a Reward Structure for mentor teachers and identified roles for all participants. The early establishment of mutual goals appeared to give momentum for positive growth. The SPDS goals included the following: (1) develop and provide multiple pathways of professional development in content and pedagogy; (2) develop, conduct, and disseminate research related to science education; (3) prepare prospective science teachers through innovative methods; (4) provide appropriate recognition and resources for the SPDS community; (5) overcome obstacles in maintaining a SPDS through effective, honest communication.

In this university–school partnership the author served as SPDS Co-director (with the high school science coordinator) and lead instructor of the university-based courses. The planning team developed a series of tasks for the prospective teachers, a list of expectations for Mentor teachers, and delineated the roles of the co-directors. Each Mentor would agree to: (1) take a SPDS intern for a whole year (September–June); (2) provide formal and informal feedback based on continual clinical observation; (3) keep a Journal both semesters; (4) participate in regular SPDS meetings; (5) participate in one SPDS graduate level course; (6) receive professional development in clinical supervision.

The anticipated advantage of forming such a partnership was improved connection between the school-based mentor teachers' practical knowledge and the college of education's theoretical base. The school-based mentor teachers played a key role in developing seminars for the prospective teachers, and contributed towards the fashioning of tasks and projects. As the partnership solidified, the school-based mentors began to take ownership of crafting the path of the prospective teachers' development. (See the systematic study of the mentor teachers' views of professional development, Kreamer, 2003.) Further, a few of the Mentors began to investigate their own practice, by engaging collaboratively with the prospective teachers in action research projects. It is for these reasons this school–university partnership had great potential for supporting a novice teacher in trying out reformed-based, innovative approaches—the kind of support and opportunity that may be absent in traditional student teaching situations.

The focus of this research is on the five prospective teachers who comprised the 2002–2003 Cohort. The field placements included ordinary science classrooms of students in grades 6–12. The term, ordinary, refers to typical high school classrooms, not funded by external grant monies.

During the course of one entire school year, the author served as instructor, adviser, and primary researcher, and examined the knowledge and beliefs and efforts of the five prospective teachers to enact teaching science as inquiry in their fieldwork classrooms. A research team of graduate students collected evidence in the form of interviews, classroom observations, and artifacts. The questions driving this study included:

(1) What were these prospective teachers' beliefs of teaching science?
(2) To what extent did these prospective teachers articulate understandings of teaching science as inquiry?
(3) In what ways, if any, did these prospective teachers endeavor to teach science as inquiry in their classrooms?
(4) In what ways did the mentor teachers' views of teaching science support or constrain the prospective teachers' intentions and abilities to teach science as inquiry?

Keys and Bryan (2001) have noted that there is little research available on high school teachers' enacting inquiry-based instruction. The importance of this study includes trying to understand the affordances and constraints, associated with novice teachers enacting teaching science as inquiry, situated in the realities of ordinary high school science classrooms.

Theoretical Framework

Three core theoretical constructs were utilized in making sense of the five prospective teachers' developing knowledge, beliefs and practice related to teaching science as inquiry: (1) teacher knowledge and beliefs; (2) teaching science as inquiry; and (3) situated learning and cognitive apprenticeship. The following section explains what I mean by these constructs, and how this study connects with the literature. Finally, I describe how the theoretical framework guided the analyses of the multiple sources of data and conclusions.

Teachers' Knowledge and Beliefs

Teachers' knowledge and beliefs are critical to the creation of classrooms in which students develop in-depth understandings of how scientists develop understandings of the world (Pomeroy, 1993; Roth et al., 1998). Knowledge and beliefs about teaching are entangled, since what one believes about teaching necessarily hinges to a large extent, on one's knowledge of his or her discipline, as well as on one's beliefs about how children learn. It is reasonable to assume that what teachers know and what teachers believe impact their decisions in planning, prior to stepping into the classroom, and in carrying out their plans, once they enter the classroom. A physics teacher acquires a foundation of discipline-specific knowledge through formal academic coursework, job-related experiences, and informal, everyday experiences. What a teacher knows about his or her subject matter; in addition to what he or she knows about what science is and what science is not; and what a teacher knows of reformed-based pedagogical strategies, shape the choice of the lesson structure. Knowledge of subject matter and pedagogy also shape how the teacher might respond to student questions and inquiries, as the lesson unfolds in the science classroom. Similar to resources used by an artist sculpturing an image of a person, a teacher draws from her depth of knowledge of science concepts, knowledge of pedagogical strategies, curriculum, children's developmental level, children's abilities to conduct investigations, how students interact in groups, and of the school context.

Knowledge has been described as being empirically based, non-emotional, rational, gradually developed, and well-structured (Gess-Newsome, 1999). Knowledge about biology, chemistry, physics, or earth science includes the ''epistemological assumption one makes about a particular domain of inquiry, that is, assumptions about the origin of knowledge, how it changes, and how truth is established with the disciplinary domain'' (Prawat, 1992, p365). In this study I define knowledge as the conceptions and understandings of science content, and content includes, in addition to the discipline-specific subject matter, the *nature of scientific inquiry.*

Beliefs, in comparison, are highly subjective, have a significant emotional component, include attitudes, and are derived from significant episodes that one experiences (Gess-Newsome, 1999; Pomeroy, 1993; Richardson, 1996; Tobin, Tippins, & Gallard, 1994). Teacher beliefs develop from a multitude of personal experiences, including episodes in classrooms and out of classrooms, and include feelings about the nature of students (Nespor, 1987). Beliefs influence the myriad of decisions that teachers make (Pajares, 1992); yet, we do not fully understand how beliefs impact practice (Kagan, 1992; Luft, 2001; Richardson, 1996). Besides having individual beliefs, teachers have entire belief systems that may be static, difficult to shift, and may be more powerful than knowledge in shaping a teacher's decisions (Bryan, 2003; Nespor, 1987). A teacher's beliefs may be complex and nested, and as Bryan (2003) determined in a case study of an elementary teacher, may constrain a teacher's ability to enact inquiry-based instruction.

Prospective teacher candidates enter teacher education programs with well-established beliefs about teaching and learning, accumulated from participating as students, for many years in science classrooms (Kagan, 1992; Nespor, 1987, Pajares, 1992; Richardson, 1996). A teacher's beliefs about how students learn can profoundly affect his or her design of instruction, as well as the role of the teacher in carrying out this instruction. If a teacher is concerned with how students make sense of science concepts, that teacher's goals may include how to promote students' deep thinking, rather than students memorizing factual and discrete information.

Teachers may hold beliefs that inquiry-based approaches support student thinking and conceptual understanding of science, but other beliefs, related to the transmission of knowledge and coverage of content, may be in conflict (Bryan, 2003; Bryan & Abell, 1999). Additionally, there are many mediating factors that serve to influence a teacher's ability to play out his or her beliefs in practice. Thus, it is important to try to understand a teacher's beliefs, and how, and in what ways, beliefs are enacted in actual teaching practice (Bryan, 2003; Luft, 1999).

In this paper I use the word, ''views,'' to describe the interplay of teachers' knowledge and beliefs—teachers' knowledge of scientific inquiry and pedagogy, and their beliefs of how children learn science, as well as the mediating factors inherent in classroom teaching. As teachers act in their capacity as decision makers, the interplay between knowledge and beliefs in making curricular decisions is complex (Bryan & Abell, 1999). Keys and Bryan (2001) suggested a line of research focused on the beliefs and knowledge of teachers related to reformed-based teaching, and they point out that ''we have little knowledge of teachers' views about the goals and purposes of inquiry, the processes by which they carry it out, or their motivation for undertaking a more complex and often difficult to manage form of instruction'' (p636). Teachers' views of learning and teaching shape their interpretations of curricular and instructional approaches (Borko & Putnam, 1994; Brickhouse, 1990; Brickhouse & Bodner, 1992; Pajares, 1992). It seems intuitive that teacher educators need to tease out the views of prospective teachers, facilitate these teachers in making their views explicit, and address these views in the context of actual classrooms.

Teaching Science as Inquiry

In order to achieve the goals of the NSES, science teacher educators must facilitate teachers in understanding the essence of science, the nature of scientific inquiry, and how to translate these understandings into the curriculum. Anderson (2002) contends that many teachers have false conceptions of inquiry. In addition to perhaps, not experiencing and understanding the processes of science, teachers may have incomplete understandings of how to teach students about inquiry. It is important to point out that the intent is not to put blame on teachers. Part of the reason for this existing situation may be the fact that researchers and teacher educators do not agree on what is meant by using inquiry in a science classroom. Inquiry is a set of interrelated processes by which scientists and students pose questions about the natural world and investigate phenomena. Inquiry is more than asking questions. According to the National Research Council, ''Inquiry is in part a state of mind, that of inquisitiveness. . .Students need to learn the principles and concepts of science, acquire the reasoning and procedural skills of scientists, and understand the nature of science as a particular form of human endeavor (NRC, 2000, p xii).''

The following aspects of scientific inquiry, derived from the NSES (NRC, 1996, 2000) were targeted in this study and served as a framework for the data analyses:

(a) Scientific inquiry involves asking and answering a question and comparing the answer with what scientists already know about the world;
(b) Data analyses are directed by questions of interest, involve representation of data in meaningful ways, and involve the development of patterns and explanations that are logically consistent;
(c) Investigations have multiple purposes and use multiple methods;
(d) Scientists formulate and test their explanations by examining evidence, and they suggest alternative explanations;
(e) Scientists often work in teams with different individuals contributing different ideas;
(f) Creativity is found in all aspects of scientific work;
(g) Scientists make the results of their investigations public.

A key aspect of teaching science as inquiry, is one of allowing students extended time to really grapple with data and to make sense of their observations, using logic and reasoning. Thus, in analyzing the nature of a teacher's instructional approach, it is important to ask, how does this teacher support students in using data as evidence? The emphases on *grappling with data* and the *use of evidence* goes beyond answering topic-centered questions, such as ''What is a cell?'' and ''What is the name of that bird?'' to developing explanations to questions, such as ''Why should I take all my prescribed antibiotic when I am sick?'' and ''Are robins arriving in my backyard earlier each spring and why?'' The nature of the environment in which prospective teachers attempt to translate their understandings of teaching science into the classroom is important, and can be studied using a lens of situated cognition and models of apprenticeships.

Situated Learning and Cognitive Apprenticeship

In this study the prospective teachers were immersed in a yearlong internship, working with professionals in a particular school culture. This study draws on the constructs of situated learning and cognitive apprenticeship as a theoretical framework for interpreting the learning environment of the teachers (Brown & Campione, 1990; Brown, Collins, & Duguid, 1989; Bruffee, 1999; Lave & Wenger, 1991; Rogoff, 1994). The nature of the teaching internship involves the collective and evolving knowledge of all participants (mentor teachers, peer prospective teachers, and university instructors). As the more experienced members (the mentor teachers and university instructors) enculturate the newcomers (the prospective teachers) into practice, the newcomers develop enhanced capabilities to perform. Finally, all participants, (prospective teachers, mentor teachers, and university instructors) benefit from new understandings. Newcomers may contribute knowledge to the experienced practitioners. Using this framework practicing mentor teachers, as well as the prospective teachers, may take on the role of learner. The construct of a cognitive apprenticeship guided the assessment of how the prospective teachers evolved as teachers throughout the year, and what factors may have influenced their evolution.

Method

The Context of Immersion in a Yearlong Internship

The prospective teachers' yearlong field experience took place in a large public high school (student population of 2600) in Eastern United States (Crawford & Kreamer, 2002; The Holmes Group, 1990). In the SPDS application process, prospective teachers submitted formal application materials the year before student teaching. The entire application process included a videotaped formal interview conducted by a panel made up of university instructors and potential mentor teachers. The mentor teachers hand-selected a prospective teacher, with whom they committed to work the entire school year. The model for teaching involved prospective teacher and Mentor co-planning and co-teaching, starting on the first day of school. We viewed the roles of prospective teacher and Mentor as overlapping, in an iterative process of developing knowledge of teaching science as inquiry.

As a component of the SPDS teaching internship, prospective teachers attended weekly seminars in a conference room at the high school. The collaborative environment provided opportunity to share personal struggles and successes with fellow cohort members. ''Collaboration is a powerful stimulus for the reflection which is fundamental to changing beliefs, values, and understandings'' (Anderson, 2002, p 9).

Given that the theoretical framework utilizes a cognitive apprenticeship, it would be ideal for Mentors to be knowledgeable and experienced in using inquiry-based approaches. However, such teachers are difficult to find, especially in a single high school. It is the author's position that this SPDS setting provided about as positive an environment as could be expected, for prospective teachers to be supported in articulating and enacting reformed-based, inquiry-oriented teaching practices.

The Five Prospective Teachers as Participants

The participant selection included all the prospective teachers in the SPDS cohort that year. These five prospective teachers were preparing to teach the following disciplines: biology, physics, environmental science, and earth science. In a process described above, the prospective teachers were hand-selected by their mentor teachers, and one might assume, were highly qualified teacher candidates. One prospective teacher was working towards attaining dual certification, and she had two different mentor teachers. All five prospective teachers differed in their undergraduate science backgrounds and pre-college experiences; but were similar, in that all had taken the same three teaching and learning courses in the College of Education. Together, they participated as a cohort. (See Table 1 for prospective teachers' backgrounds and match with Mentors.) All five prospective teachers signed Human Subjects informed consent forms, and agreed to be interviewed. Prospective teachers submitted evidence of their work, including a 10-day inquiry-based unit, designed and field-tested in the spring semester. All names of prospective teachers and Mentors are pseudonyms.

Data Collection, Analysis, and Interpretation

This study used a multiple case method and cross-case comparison design to determine commonalities and differences among the five interns (Creswell, 1998; Merriam, 1988). The

Table 1
Backgrounds and placements of five prospective teachers

Prospective Teacher	Certification Area	Grade Level	Prospective Teacher's Prior Research Experiences	Mentor	Mentor's Participation in SPDS Inquiry Grad Course
Jason	Physics	12	None	Aaron, 11–12th, East Building Physics	Yes
Katherine	[Dual certification] Environmental Science	11–12	None	Derek, East Building Environmental a.m.	No
	Earth & space	9		Jacob, West Building Earth & Space p.m.	Yes
Carrie	Biology	10	None	Dustin, West Building Biology	Yes
Josephine	Biology	10	Limited-molecular evolution lab; computer data entry during sophomore year	Jim, West Building Biology	Yes
Helen	Earth & space	9	None	Frank, West Building Earth Science	No

purpose of the case study research was to explore in depth these prospective secondary science teachers' developing understandings of scientific inquiry and their views of teaching science as inquiry, within a particular context. Multiple data sources included: (a) in-depth semi-structured interviews of the prospective teachers, administered towards the end of the school year by a research assistant; (b) semi-structured interviews of Mentor teachers, conducted by a doctoral student; (c) inquiry-based units planned and actually carried out in classrooms; (d) researcher's journal documenting meetings, informal conversations, and classroom observations.

An inductive method (Erickson, 1986) and strategies suggested by Creswell (1998) and Merriam (1988) were used to analyze the various data sets. First, all semi-structured interviews were transcribed and coded for references to elements of teaching science as inquiry, using the aspects of inquiry described in the theoretical framework. Second, Mentors' views of professional development and inquiry were taken from the findings of a concurrent study (see Kreamer, 2003). In the Kreamer study the nature of each Mentor's stance towards science instruction was systematically determined using the software ATLASti (1997). In analyzing Mentors' transcripts, we used an open-coding process, rather than looking specifically for instances of elements of inquiry, and eventually developed six emergent dimensions: benefits, barriers, roles, goals, preparation, and support. In this way, we could better characterize Mentors' instructional stances, rather than using predetermined codes. Third, the prospective teachers' planned units were analyzed for the level of inquiry (level 1, 2, or 3), using a content analysis rating scheme based on a table of essential features of inquiry in Inquiry and National Science Education Standards, (NRC, 2000). (See Appendix B) Fourth, the author's journal notes were read, re-read, and coded using word processing, for comments and incidents related to teachers' views of inquiry. In this case, the author looked intentionally for incidences in which prospective teachers or mentors mentioned dilemmas and successes, related to attempts to plan and carry out teaching science as inquiry.

Triangulation of the data sources (SPDS application background data; analyzed transcripts, ratings of the inquiry units (see Table 2); and the analyzed author's journal notes) all contributed towards developing a profile for each prospective teacher. Each profile considered background, views and understandings of scientific inquiry, and evidence for planning and teaching science as inquiry. These profiles and Mentors' stances were arranged in a matrix, using a technique

Table 2
Interns' level of enactment of inquiry-based designed unit plans

Intern	Grade Level	Unit Topic Driving Question Spring 2003	Unit Goals Related to Inquiry	Unit Lessons Related to Inquiry	*Level of Inquiry
Jason	Physics 12	*The Nature of Waves:* What determines their fundamental properties, and; what determines and changes their movement?	• Apply concepts of models as a method to predict and understand science and technology • To evaluate and predict the motion of waves in a variety of circumstances • Evaluate appropriate instruments and apparatus to accurately measure materials and processes	• Students investigate the periodic nature of pendulums • Ss determine things that may change its motion (length, mass, angle). Students collect data—Students analyze data and prepare whiteboards	3
Katherine	Environmental Science 11–12	*Aquatic Ecology*: What do trout need to survive and reproduce in streams in Pennsylvania?	• Generate a scientific question that could be answered as part of the field trip to a stream • Generate a procedure to answer their questions • Communicate answer to others • Understand how humans have impacted major stream components	• Ss will figure out a question to investigate on a field trip • Ss will travel to various points along the stream and conduct tests to answer the question • Ss will work in teams on one aspect of the stream	3
Josephine	Biology 10	*Mitosis, Meiosis, and Cancer:* Why are we many smaller cells instead of one big cell?	• Use process skills to make inferences and predictions • Create and organize data table and draw conclusions	• Onion root tip lab- graph/identify amount of time cells are in each stage	2

(*Continued*)

Table 2
(Continued)

Intern	Grade Level	Unit Topic Driving Question Spring 2003	Unit Goals Related to Inquiry	Unit Lessons Related to Inquiry	*Level of Inquiry
Carrie	Biology 10	*The Cell: Mitosis and Uncontrolled Cell Growth*: How do cells grow and divide?	None (use the microscope and project the onion root tips onto the TV screen; have the students tell you what stage of mitosis each cell is in)	• The second half of lab Ss determine time each cell spends in the different stages of mitosis; they have four questions to answer, as well as graphing their data against the class average data	1.5
Helen	Earth and Space 9	*Astronomy*: How does the earth fit into the larger system-the universe?	None	• Students make their own graphs based on real star temperatures and absolute magnitudes	1

*Rating based on the following: 1, closed or highly structured; 2, guided inquiry; 3, full or open inquiry, based on framework derived from using the levels of inquiry NSES (1996; 2000) described by Miles and Huberman (1994). The displayed profiles contributed to developing cases of each prospective teacher-mentor. Finally, determination was made of each prospective teacher and Mentor's position on a continuum. Two graduate students collaborated with the author on appropriate placements on the continuum. Adjustments were made, following discussions, until consensus was reached. In this way, the author endeavored to develop a cross-case comparison of the five prospective teachers, in order to develop an evidence-based explanation for why some designed and enacted inquiry-based instruction in the context of the SPDS, and why others did not.

Role of Researcher

The author's extended participant observation (over 2 years) contributed to the internal validity of the study. However, it is important to raise the issue of bias within the study. As Co-director of the SPDS, I recognized that I had a vested interest in the school–university partnership. Contributing to my students' (the secondary prospective teachers') understandings of inquiry, and my agenda to support teachers' understandings and enactment of inquiry-based approaches, are important components of my research and teaching. As a classroom teacher, I had studied my own efforts to teach science as inquiry (Crawford, Krajcik, & Marx, 1999). As a way to lessen the potential for bias and skewing of the data interpretation, graduate students independently administered and assisted in analyzing all interviews.

Overview of Five Cases of Learning to Teach Science as Inquiry

Despite the similarity of setting (same high school, instructor, and university supervisor), it became apparent that, when the year ended, the five prospective teachers enacted very different kinds of teaching practice. From analyzing the interviews it was evident that the field experiences these five prospective teachers encountered during the year greatly shaped their ideas. These experiences (the totality of the setting; including varying abilities of students in their classes; the students' roles in their classrooms; and the mentor teacher's stance) appeared to contribute towards an increasing skepticism about the feasibility and viability of using reformed-based ideas. This skepticism became evident, despite the fact that the prospective teachers had been immersed in reformed based ideas in their on-campus methods courses. Of equal importance, and perhaps even more significant, is the fact that each prospective teacher espoused a different view of inquiry and varying level of understanding of what it means to teach science as inquiry.

All five prospective teachers began the school year with enthusiasm, and they appeared poised to design inquiry-based lessons (author's personal journal, 8_02). This enthusiasm for reformed-based instruction began to wane and, in some cases, to eventually disappear. The factors dissuading them, identified by the prospective teachers themselves, included the following: an increasing responsibility for taking on more and more teaching tasks; the students in their classrooms resisting new methods of instruction; and the Mentor's degree of openness towards using inquiry approaches. The mentor teachers' beliefs and preferred pedagogical approaches appeared to deter at least some of the prospective teachers from deviating from the Mentor's established classroom culture. This reluctance existed, despite the fact that the five SPDS Mentors were cognizant of the university's emphasis on using an inquiry approach. In fact, four of the six Mentors had participated in a university course, Teaching Science as Inquiry, taught by the author during the previous year.

Most of the prospective teachers admitted they were concerned about the risk of creating inquiry-based lessons. Some felt fearful of teaching their original lessons and deferred to their mentor. As expressed by one prospective teacher, "my mentor already has ideas about how to teach a certain lesson.'' These reluctant prospective teachers expressed concern that they did not want, as one put it, ''to step on any toes.'' Evidence of an unwillingness to take the risk includes Helen's statement. ''When I realized that my teacher was a traditional style teacher who favored direct instruction, cookbook lab, and worksheets, I was discouraged and very pessimistic'' [Helen, Earth Science Intern, Interview, April 2003].

A reluctance to try out an inquiry-based approach could not be explained by the single factor, the Mentor's instructional stance. There was evidence that some Mentors declared they were open to trying out new teaching approaches. One Mentor, Jim, expressed that he encouraged his prospective teacher to experiment with inquiry-based approaches. Further, Jim stated he was receptive to changing his own teaching.

> Interviewer: What have you tried this year in the classroom that was new?
>
> Jim: I tried inquiry teaching.
>
> Interviewer: Have you changed the way you think about your teaching this year?
>
> Jim: . . .I do think I tried some different things to get to that. . .to get to that point that I want to be at [Jim, Biology Mentor, Interview, 8/2/02]

In spite of this expressed openness towards change, Josephine, was hesitant to try out new approaches. Furthermore, Josephine was unable to clearly articulate how one might actually carry out such an approach. Despite Jim's proclaimed willingness to allow her to try out innovative approaches, Josephine became more and more reluctant to use such strategies as the year went on.

In another case the Mentor was open to allowing his prospective teacher to take the lead in planning inquiry-based instruction. A mitigating factor was that the Mentor himself was a beginning teacher, in his third year at the high school. The Mentor was not particularly knowledgeable, about how to support his intern in what it means to teach through and about inquiry. Yet, the prospective teacher Jason had a strong disposition towards inquiry; and by many accounts he was successful in planning and carrying out inquiry-based instruction.

> Jason: . . .I like the nature of science type of thing; I think that it's important the students learn it. . .If you're just lecturing all of the time and talking about theory and using like problems, then they're missing out on the whole big experimental part. . .which is really the bulk of science work. . .I like the idea of having, like a project, where they actually use what they've learned to do something. I made a kind of monocular. You can do things with, like prisms. So that they can apply what they've learned now, what they've made, through the observations. . . [Jason, Physics Intern, Interview, 5/03].

In Jason's case it was evident that his own knowledge and beliefs were critical to successful enactment of an inquiry-based approach, combined with his Mentor giving Jason the freedom to try out different approaches. The following cases provide evidence of the critical factors, which appeared to contribute towards these five Interns' differential practices.

The Spectrum of Cases

The actual practices of the five prospective teachers represented their diverse interpretations of what it means to teach science as inquiry—their interpretations of teaching science as inquiry displayed a range of practice, from very traditional, lecture-driven, non-inquiry-based instruction to innovative, open and full-inquiry projects. Figure 1 displays the relative views and practices of the prospective teachers and relative stances of Mentors, constructed from analyses of the bulk of

Intern's Views of Inquiry

Uninformed	Intermediate	Informed
-------- Helen -----------------------Carrie ----- Josephine -------------------------------Katherine---------------Jason		

Mentor's Stance Towards Inquiry

Traditional /Closed	Intermediate	Inquiry/Open
Helen's -----------------------Katherine's 2nd -- Jason's - -Katherine's 1st ---------------Carrie's ----Josephine's		

Intern's Enactment of Inquiry Instruction

Traditional	Intermediate	Inquiry
Helen--------------------Carrie------------Josephine---------------------------------------Katherine-----------------Jason		

Figure 1. Relative positions of Intern's views of inquiry, mentor's stance towards inquiry, and Intern's enactment of inquiry.

the data. The following cases provide evidence for decisions to situate the prospective teachers and mentors at varying positions on the continuum.

Jason, the Most Inquiry-Based Intern—Students Were Really Interested in Why

Following is the case of Jason, a prospective physics teacher. Jason had experience tutoring students in the English as a Second Language program in this SPDS high school. He had no previous science research experiences. Jason's goal statement in his SPDS application stated, "I will also emphasize the inquiry nature of science to prepare students for higher level learning in science or other disciplines." Jason planned and carried out instruction closely aligned with teaching science as inquiry. The evidence included Jason's lesson plans, actions in the classroom, as well as assertions about his own practice. When asked why he believed in using inquiry-based instruction, he attributed it, not to his undergraduate coursework, but to his former high school physics class. He emphatically stated that the labs at the university "were terrible" and "definitely not inquiry-based."

Jason exhibited high energy level and self-confidence. Progress reports from his Mentor and his University supervisor were consistently very positive. During one SPDS meeting, his mentor acknowledged that, not only was Jason more than meeting all program expectations, his Mentor was also learning from Jason. One example included Jason initiating setting up an after school club. Jason mentored a small group of young women and men, in constructing an ancient device known as, a trabouchet. After working on calibrating the device, they demonstrated it in the Middle School Renaissance Fair.

For his regular and AP physics students, Jason developed several units in which he engaged his students in both guided and open-inquiry. Jason wrote:

> This unit focuses on the nature of waves: what causes them; what determines their fundamental properties. The unit will begin by studying vibrations such as those associated with pendulums and springs. The principles governing the periods of those oscillators will

> be examined, followed by a deeper investigation into their motion. That will lead to the sinusoidal equations that can be used to predict the motion of simple harmonic oscillators, such as springs and pendulums.

He explicitly connected sections of his unit with aspects of scientific inquiry:

> Though quantitative analysis will not be the primary focus of the unit, it will be present, and students will have the opportunity to collect data about the functioning of pendulums and determine what relationships exist. This should give them insight into and an appreciation for the scientific process.

One of the goals in the sophisticated, well-crafted unit included, "students will understand that scientific explanations must meet certain criteria. First and foremost, they must be consistent with experimental and observational evidence about nature, and must make accurate predictions, when appropriate, about systems being studied. They should also be logical, respect the rules of evidence, be open to criticism, report methods and procedures, and make knowledge public."

In one lesson Jason's students were involved in grappling with data, in developing explanations for different results, and in asking questions. The lesson objectives included investigating the concept, momentum, through playing with marbles. The following excerpt illustrates Jason's views and his enactment of inquiry.

> Jason: Well I can think of one lesson I taught...there's a really interesting thing that happened...the marbles all should have been the same. But...one group had, like, 80% kinetic energy...80% of the potential was transferred into kinetic. And, then another group...it was more like 60%....So, one thing that the students were really interested in was, "why, when we have this, these same objects, are we getting two different sets of answers?"...Shouldn't they be the same? So, we tried to come up then with, like an explanation...We didn't come up with anything definitive. But, they *thought* about it. And it was a question that they asked, not one that I asked [Interview, April 2003].

Jason described how his students found a discrepancy in the data, and noted his students asked questions of their own accord. He emphasized the importance of encouraging students to think.

In another example, Jason planned and taught a unit related to electricity. Jason recognized the power of having students explore and try things out.

> Jason: And, like with the electricity circuit project, one thing that some of the kids liked to do was to see what would happen. They've got the power source. They've got some wires. "Gosh, what happens if I test a pencil?" "What happens?" and the pencil catches on fire. "Why does this happen?" It wasn't what I told them to do, but they were actually experimenting and trying to figure out some sort of. I let them do it [Interview, April 2003].

Jason explicitly addressed the sociocultural aspects of scientific inquiry in his teaching, as evidenced by this excerpt:

> Jason: I try to draw some parallels. Um, one of the things that I do sometimes is, when there's a big problem, like a big lab experiment, instead of having all the students do all the steps ...we break it up so that, like one team is working on one aspect, another team is working on another aspect...and I explain... this is a lot of times what scientists do; instead of having...one group of scientists working on everything about a problem, they kind of divide it up into different areas ... [Interview, April 2003].

Jason also recognized difficulties, and he reflected on when things go wrong. ‘‘I think whenever you try something different that you haven't tried before, it's a risk. Because it could blow up in your face, or it could go well. Two classes kind of blew up in my face, and in one class, it went well’’ [Interview, April 2003].

As Jason stated graphically, ‘‘it could blow up in your face.’’ Jason also expressed reservations related to the classroom culture and role of the student. ‘‘If it's so many small bits of inquiry, the students handle it better than lots of like more, open inquiry. I think that's just due to what they've experienced beforehand. They just haven't had enough practice with it’’ [Interview, April 2003].

Jason's Mentor's Stance Towards Inquiry

There was evidence that Jason's mentor afforded him a great deal of freedom to plan and teach inquiry-based lessons. ‘‘For the most part Aaron (Mentor teacher) has been good about letting me kind of decide how to teach’’ [Interview, April 2003].

This is not to imply that his mentor teacher openly embraced using an inquiry-based approach. For example Jason stated, ‘‘I know that he's not real comfortable with inquiry; at least, he wasn't prior to this year. And, I like to do lots of labs that involve that sort of thing, um, because they're more fun for me, and the students, I think’’ [Interview, April 2003].

Jason's mentor was undecided about the effectiveness or appropriateness of using an inquiry approach in teaching his senior level physics students, and he was just beginning to explore this kind of teaching. During monthly SPDS meetings, Aaron expressed some confusion about how one might re-structure a physics laboratory activity (author's journal, 12/05/2002). Further, Aaron was still exploring his own strengths and weaknesses as a third year teacher.

Helen, the Least Inquiry-Based Intern—In Survival Mode

In contrast to Jason who appeared knowledgeable, capable, confident, and free to explore using inquiry-based approaches, Helen represented the opposite end of the spectrum. Helen had a rocky start to the year. Her Mentor expressed concern and reservation about Helen's subject matter competency. Helen admitted she was having difficulty passing the initial teacher examination in Physics, her second certification area. And, she had to work hard reviewing, and even re-learning, the earth science concepts in the school curriculum.

Other issues emerged, including a claim by Helen that her Mentor did not give her the same professional respect a male counterpart might be afforded. Non-academic issues included a conflict with her Mentor's, her university supervisor's, and her own interpretation of the school's dress code. All in all, Helen struggled to keep up with the demands of meeting typical student teaching expectations. During the first semester Helen initiated several help sessions with her university supervisor. Helen described her frustration, with working with her Mentor and her insecurities in teaching. During the end of the year interview she admitted her reluctance to involve her students in inquiry. When asked if she was doing any inquiry-based lessons, she responded, ‘‘I think they're few and far between. It's not something I think about, honestly. I'm just trying to get by . . . ah. . . Right now, I'm in survival mode. That's like day-to-day. (Helen laughs)’’ [Interview, April 2003].

When asked, ‘‘How do you believe that students learn science best?’’ Helen responded,

> Helen: By being entertained. I think you, uh. Seriously, if you, ah, adhere to most of their senses. If you can bring in sight, sound, touch, taste, smell. If you bring in as many as possible, they'll learn more.
>
> Interviewer: How would you do that?

> Helen: Um, I don't think you can do it with everything. But I. . .I try to pull in a lot of visuals, like interesting pictures. We're doing volcanoes now. So, uh, I like to bring in pictures of volcanoes, active volcanoes. Ah, they really enjoy, I think, aesthetics. I don't think you can stand in front of a class, in lecturing, expect students to get information from that. I can't even stand myself talking [Interview, April 2003].

Helen believed in the importance in using visual kinds of data to help students to learn. It is not clear, if Helen viewed the use of the senses as a cognitive means to engage her students in inquiry, or if it was primarily for motivational purposes.

Helen designed a unit on Astronomy that began in mid-February and ended in mid-March. Helen initiated her unit by lecturing to her students on the different signs of the zodiac. Throughout her unit she used many devices for helping her students to remember various facts. These devices included the know-want to know-learned (K-W-L) chart technique used in language and literacy. Her entire written unit filled over 300 pages. The majority of her lessons were teacher-directed and offered limited opportunity for students to engage in asking their own questions, working with data, or developing their own explanations.

Helen's Mentor's Stance Towards Inquiry

Helen's Mentor, Frank, was new to the SPDS program. Frank had agreed to mentor Helen, but only following a special request by Derek, the Science Coordinator. Frank had not participated developing the SPDS, nor had Frank participated in the graduate level course, Teaching Science as Inquiry. Nevertheless, Frank had hosted several non-SPDS pre-student teachers from the university. Therefore, it was assumed Frank was acquainted with the overall philosophy of the teacher education program.

Helen perceived she had limited opportunity in trying innovative approaches.

> Helen: My mentor teacher has his own mindset of where things should be going. . .I have pretty strict guidelines.
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> Interviewer: How much freedom do you have to change the content or change the way to, you teach things?
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> Helen: I don't have any freedom to change the curriculum at this point (laughing). I'm under, I don't want to say a dictatorship. But, ah, you know. He, he has his own mindset of what, where things should be going and what things should be taught in that amount of time. So, I have pretty strict guidelines [Helen, Interview, April 2003].

Helen's perceived support for innovation appeared to be in direct contrast to that provided to Jason. Despite her rocky start, Helen and Frank's professional relationship clearly moved towards a more positive one. Helen's Mentor eventually supported her in collaborating on an action research project. They co-presented their findings at the annual PDS Inquiry Conference in May. There was evidence that Helen's mentor became more open to her exploring different ways to teach. Even so, Helen exhibited little, if any, movement towards trying out reformed-based approaches.

Josephine, an Intern Conflicted With Inquiry Teaching—Start Off on Small Levels

Josephine exhibited a mixed view of teaching science as inquiry. Although she articulated a vision of students asking their own questions, Josephine declared she was concerned with meeting rigid standards, During her interview Josephine admitted that she recognized many constraints to using inquiry-based approaches, including her perceived need to cover national and state education standards. These perceived issues appeared to prevent her from engaging students in the kind of learning environment she envisioned.

> Josephine: When it comes to implementing those questions in the classroom, I had problems working like this, because questions people have aren't that related to what needs to be covered by (the state) and National standards. They (standards) are very specific, as to what they want covered. And students may have very interesting questions. But then you go, ''well that is very interesting, but you need to do that on your own.'' Because, here in class, I have to go by the objectives and the agreed objectives of me and my mentor, and what the (state) standards say I need to teach. That is a very strong cause of conflict, I think [Josephine, Interview, April 2003].

When pressed to explain what she meant by the teachers' use of students' ''very interesting questions,'' Josephine remained vague and struggled with giving a specific example.

> Josephine: The question they come up with shouldn't be like a yes/no. . .I really like the why questions—why does this happen or how does this happen?. . . Cause, I think when you ask why and how, it answers all the when, where, and who questions within it. . .I prefer questions that sort of have that order [Josephine, Interview, April 2003].

When asked to describe her view of how people learn science best, Josephine appeared torn between balancing addressing the standards and willingness to explore new theoretical ideas about learning and teaching.

> Josephine: Well, we have been taught in all our educational theory classes that everybody learns things differently. And you have to prepare for those different learning styles by coming up with a variety of things for each concept that you are going to teach. Except, when it comes to science. I do think that people learn best when they have their own question. And they go out and research it on their own. I do think that is true. That is what works for me [Josephine, Interview, April 2003].

Josephine referenced different theories of learning, gained from her education coursework, and connected learning with a pedagogical strategy of allowing students to ask questions in science class. Yet, she had difficulty reconciling how to enact these theories in her own practice. When asked to give an example of an inquiry lesson she taught, she responded. ''There is nothing I could think of, off the top of my head, either of what Jim did all year, that would be complete inquiry. When I think of what complete inquiry is, as I said, students come up with their own questions and research it to its entirety until they have a conclusion'' [Interview, April 2003].

Josephine described an attempt to modify a standard laboratory investigation, that had been structured and closed-ended, to one in which the procedures and results were left open.

> Josephine: What we have done is start off on small levels and coming up with labs where they can choose between a few different questions. Not give them the data tables that they are supposed to come up with, not give them the results. So we give the lab before we teach it. . . things like that. Keep things a little bit open-ended, so that students have the mind set that if their results are wrong, their practice or their procedures were wrong. . ..It is O.K. if your results are different from that group, because you had a different procedure. So, this is something that happens in science. Don't worry about it [Interview, April 2003].

Josephine's mental image of what it means to teach science as inquiry was shaped by her undergraduate experiences.

> Josephine: Once I got to larger biology classes where there are hundreds of people in one class I would just, to be honest, I fell asleep most of the time. I felt bad, because this is what I am supposed to be interested in. But, the way it was presented and the professors were so boring. . .I did think they could make this so much more interesting, if he just explained it this way or used a different example. . .So, I have always tried to find my own personal spin on the information, so that I could learn it. That is pretty much what I have done through most college science courses [Interview, April 2003].

Josephine revealed from working in a research laboratory as an undergraduate, she gained a negative impression of scientific work. Josephine identified the tedious aspects of scientific data crunching.

> Josephine: I did my independent study last year. . . in the molecular evolution lab. What I did, in theory, was very interesting. But, the actual data collection was really mind numbingly dull. I just copied and pasted amino acids from different computer programs and spent hours on that. The computer did all the work for me, but it wasn't until hours and hours later, I had to think about what the results meant. I like more active thinking [Interview, April 2003].

Josephine's Mentor's Open Stance Towards Inquiry

Despite Josephine's hesitancy towards teaching science as inquiry, her mentor was very open trying out new approaches. Further, Josephine's Mentor was open to changing his own practice.

> Jim: I want to change things. Well, rethinking. I want to explore inquiry-based learning, whether or not it's useful. In general, and to me, specifically. I like it on the outset. Reading more about it, as part of this SPDS thing going on, and as part of it in the class I'm taking with (the author) and reading a lot more about it.
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> Interviewer: And how do you plan on accomplishing this?
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> Jim: Oh, huh, I have an intern (he laughed). We work together on this. She's ah, she actually knows more about it than I do. Um, she has done her block courses and everything she's done so far in science education (at the University) has been inquiry learning, for the most part. They haven't taught her anything else. So, I'm relying on her and her knowledge base to improve mine, and then, by working together. And, we actually change a lot of what I do in the classroom, especially, lab-based. Experiential, that's how I plan on going about it. And so far, we've done a lot of things to change things around [Mentor Interview, Kreamer, 2003].

Jim forthrightly stated he was actively open to change in his classroom. Jim acknowledged that, "we work together." A former graduate of the University's teacher education program, Jim anticipated that he could learn from his Intern. "Ah, she actually knows more about it than I do."

Jim was involved in the initial planning phases of the SPDS. Additionally, Jim had attended two national education conferences with the author, one a Holmes Schools conference in Arizona; and a second, a conference of the Association for Science Teacher Education (ASTE), in which he and the author co-presented a paper on initiating science professional development schools.

Jim was open to perusing the inquiry-based landscape, and he viewed working with his prospective teacher as a main vehicle for change. ‘‘I’ve changed it to inquiry based. Good things, bad things, things to think about when it comes to inquiry. So, that’s how I plan on going about it. Using her. (He laughed.)’’ [Interview, Kreamer, 2003].

Jim valued Josephine as a co-teacher, and it was clear he supported her development. There is ample evidence that Josephine’s mentoring environment provided fertile ground for her development as a reformed-based teacher.

Carrie, an Intermediate Inquiry-Based Intern—It Does not Matter Which Way You Teach

Carrie openly admitted she had limited knowledge of teaching science as inquiry and of the nature of scientific inquiry. She stated, ‘‘the problem is the science education department tells you inquiry is a great approach to take, but nobody ever teaches you inquiry. I have never experienced inquiry *per se*. Yeah, but if you were to say to me, think back on your experiences in the lab, would you consider them inquiry based? I would say, no.’’

Carrie’s views of using inquiry resembled those of Josephine. Like Josephine, Carrie was placed at an intermediate position on the inquiry continuum. There was limited evidence in her spring instructional unit of involving students in any phase of inquiry. Carrie designed a 13-day unit on the topic of Mitosis. Her driving question was, ‘‘How do cells grow and divide?’’ Sub-questions were: (a) Why can’t cells simply grow by increasing in size? (b) What are the possible consequences of uncontrolled cell growth? (c) What occurs in the process of mitosis? (d) What are the stages of the cell cycle?

All unit goals related to primarily fact-based science content. There were no goals directly related to learning how to do inquiry or learning about inquiry. Her lesson plans involved students taking notes during lectures, or participating in hands-on activities. One objective was, ‘‘students can be taught that it is not possible for cells to simply grow by increasing in size.’’ She addressed this objective by having students do an activity with yarn and various sized balls. Students measured the circumference, surface area, and volume of four different sized balls. In her lesson reflection, Carrie wrote,

> After we discussed these answers, I put a mathematical description of why cells cannot grow simply by increasing in size on the board. I think this was a good idea, and I would do it again. I wanted the students to see for themselves, that as you increase the size of a cell, the surface area does not increase at the same rate. I did not want them to take my word for it. I wanted the students to prove it to themselves [Carrie, Lesson reflection, April 2003].

The one lesson most closely aligned with inquiry involved the use of observational data. Carrie wrote, ‘‘Students learned to identify the stages of mitosis by looking at onion tip cells projected on a large monitor.’’ This lesson resembled one by Josephine. But, Carrie’s lesson was more structured, teacher-centered, and it focused primarily on facts. Carrie wrote, ‘‘using the video microscope allowed us to display to the entire class what a cell in metaphase would look like. This allowed the students to then, get their own scopes, and try to find a cell in the same phase. It saves a great deal of time as well as makes the lesson easier to teach.’’

On the one hand, Carrie's view of learning to teach science included the need to modify instruction for diverse learners. "I think different kids learn differently. Some kids actually sit there and do the problems. Some kids actually have to have hands-on experiences. . .You need to spice it up" [Carrie, Interview, May 2003]. On the other hand, Carrie offered many reasons why she believed an inquiry-based approach just does not work most of the time. Carrie underscored her views by using her recent classroom experiences; teaching 10th grade college-bound and non-college-bound biology students.

> Carrie: I sometimes look at my kids and I am like, it just can't be done with this lesson, because they would not get it. . . .Plus, I do not think high school kids want to figure it out themselves. They are very reluctant to do that. They want you to give them the answer. They say, "Tell me how to do this," because they are concerned about their grades, or they are lazy, or they just want to get through it. . .I mean just from my experiences in the high school. We did a lab with them on this buffer system. And, we told them that you were supposed to mix this with this, and they dropped their jaw. . .[Carrie, Interview, May 2003].

In addition to identifying the nature of her students as deterrents, Carrie recognized the great demands on the teacher. "It is very difficult. . ..But, I mean, you have to know so much about each topic [to be able to enact inquiry]. But then, some people say, that is the whole thing about inquiry, you guys will learn together" [Carrie, Interview, May 2003]. Carrie cited constraints similar to those noted by Josephine, including the need to cover the same material and give a common final examination.

> Carrie: We [teachers] are only allowed certain amount of time. Each person (biology student) has to get the same midterm and the final. So, therefore you have to cover the same amount of material. It does not matter which way you teach it, as long as you provide the same information to each student. The teaching method does not have to do anything with it. I just think it [inquiry] takes so much more, so much time [Carrie, Interview, May 2003].

Carrie viewed her main goal as "cover the same amount of material." She stated she did not believe that one approach; for example, an inquiry-based one; is better than any other, for developing a student's understandings. She claimed that, "It does not matter which way you teach." This statement strongly suggested her failure to understand a rationale for selecting one approach over another, dependent on one's instructional objectives.

Carrie's Mentor's Stance Towards Inquiry

Like Josephine's mentor, Dustin was involved in crafting the SPDS. In his own words, "I'm a strong proponent of the SPDS program." Dustin explained the advantages of the SPDS. "What it's, hopefully what it's doing for our interns, but what also it's doing for me as a mentor participation, participant in that program. . .What stands out is just, I just think it's a unique opportunity" [Dustin, Interview, March 2002]. Similar to Jim, Dustin was very supportive of his prospective teacher. Dustin consistently reported on Josephine's positive progress through the year. He emphasized how important she was to his own teaching. "I mean. . .it's, it's hard to imagine at this point, going through a whole school year, not having an intern" [Dustin, Interview, March 2002].

Dustin anticipated his own professional development would evolve from working with his SPDS prospective teacher, "I'm hoping she brings in some fresh new ideas, ah, into the classroom.

I'm hoping she helps me develop some, redevelop some labs, in the collaborative sense'' [Dustin, Interview, March 2002]. At the end of the year, he attributed trying out new approaches to his prospective teacher. When asked what he had tried that was new, Dustin responded, ''Now let's see, that's really what (my prospective teacher) brought into the classroom. Um, we did do, I'll say some inquiry-based ah, lessons that I wouldn't have tried on my own before...'' [Dustin, Interview, March 2002]. The author's frequent conversations with Dustin confirmed he was exceptionally supportive of his prospective teacher and receptive to trying out new instructional approaches in his biology classroom.

Katherine, a Reserved Inquiry-Based Intern—I do not Necessarily do it Effectively

Katherine began the school year admitting she was uncomfortable with teaching students in her non-college bound environmental science classes, although she appeared comfortable with the subject matter. In her SPDS application, Katherine expressed her personal connections with one of her certification areas, environmental science. ''I have also gotten a lot of joy from nature and the outdoors.'' She mentioned that in the future, she might teach science in a non-traditional setting, as an outdoors interpreter. For her undergraduate Honors College project, Katherine developed an assessment of elementary children's understanding of ecology, in the context of an outdoor education camp.

Katherine designed and taught a unit that contained several essential elements of inquiry. Her unit was rated a level 3, using the framework derived from the NSES (see Appendix B). As a centerpiece, her unit involved students conducting a field study of a nearby stream. Katherine developed a driving question related to trout. She believed the question was relevant and student-centered, as many of her students were interested in hunting and fishing. In contrast to her plans for inquiry-based instruction, Katherine's belief statements about using inquiry were largely negative. Katherine's reservations about teaching science as inquiry related to the nature of her students. In her environmental science classes, students typically had limited academic abilities, low achievement, and exhibited low motivation.

> Katherine: I think that kids are so used to school, that they don't really like to think. I have tried to do things like that (implementing inquiry-based pedagogies). Everyone is just kind of like, ''What are we doing? What do you mean?'' At this point, they want the directions given to them as clearly as possible. They do not want any uncertainty. They do not want to think about anything...They want to copy the definitions right out of the book and complete the worksheet. If there is any question that makes them try and use their knowledge, think a little, I have to explain it to them, because they do not know the answer. I do not know how to get over that mindset...They are afraid of being wrong [Katherine, Interview, May 2003].

Katherine described her students' resistance to learning science as inquiry, and her attempts to support her students in grappling with data.

> Katherine: The whole time that we were doing a lab they would be like, ''Is this what I am supposed to get?'' (I would say), if that is what you are getting, that is what you are getting. It doesn't matter if you are supposed to be getting something else. The point is, data you get is the data you get. Regardless of whether you messed something up. It has been really difficult to get them past that. They always want to know exactly what to do [Katherine, Interview, April 2003].

In addition to the nature of the student's role as a deterrent, Katherine expressed a lack of confidence about her own knowledge and abilities to use inquiry.

> Katherine: I can't necessarily think of an inquiry activity to go with every topic. . .Partly, because I do not necessarily do it effectively. Partly, because we come into a system that is already set up. A lot of the activities that I suggest are like, ''Well, probably that would not work'' (by my mentor teacher). Also, there are labs already created, so it feels stupid to try and create a new one, when there is already one that does the same thing [Katherine, Interview, April 2002].

Katherine admitted she did not want to take a chance that she might fail in her attempts to use inquiry. ''It is risky you know, if it would fail. You are not going to fail with the lecture, but you might fail with an inquiry activity'' [Katherine, Interview, April 2003].

Katherine's Mentors' Stances Towards Inquiry

Katherine felt that she served two masters. She worked with one Mentor in the morning environmental science classes, and a second Mentor in the afternoon earth science classes. Derek, Katherine's morning mentor, served as head of the 35 personnel science department, a half time appointment, and as the SPDS Co-director, with the author. At the beginning of the school year, Katherine honestly admitted that Derek intimidated her. Derek espoused using an inquiry approach. But, in fact, his view aligned more closely with hands-on science learning. Derek was not particularly open to changing his teaching. Derek declined from participating in the Teaching Science as Inquiry Course offered to the mentor teachers. Derek's teaching style, developed over the previous 25 years, could be characterized as forceful, direct, and primarily teacher-centered, his lectures interspersed with structured, hands-on activities.

Katherine's earth science mentor, Jacob, did not articulate a definitive stance on inquiry. In a paper for the graduate level course, Jacob wrote, ''science understanding needs to be built from the ground up, and should include core concepts, like the trunk of a tree.'' Instead of addressing the aspects of inquiry-based instruction, he reacted to a recent school-based movement towards teaming and interdisciplinary teaching in his grade level of 9th grade. Jacob wrote, ''science instruction should not be driven by team-oriented strategies, such as interdisciplinary units.'' It was difficult to identify his exact position on the inquiry continuum, from either conversations or his writings. Since he never specifically articulated his views, his stance was determined to be traditional, centered on acquisition of discrete concepts using teacher-centered instruction.

In the next section, the five prospective teachers' beliefs and knowledge are compared with their mentor teachers' stances towards inquiry.

Discussion

In what ways, if any, did these prospective teachers endeavor to teach science as inquiry in their classrooms? Results indicate that the teaching strategies used by the five prospective teachers represented an entire spectrum of practice—from traditional, lecture-driven lessons, to innovative, open, full-inquiry projects. This wide range of practice maps directly onto the research of Windschitl (2003). Despite being immersed in a cohort experience in learning about, and working with, aspects of how to teach science as inquiry, and despite having Mentors well acquainted with the goals of the preservice program, these prospective teachers demonstrated widely varying practice. This study differs from Windshitl's, in which he states, the Mentor teachers were an ‘‘under-examined piece of the explanatory puzzle’’ (2003, p 139). In the present study, I was well acquainted with the views and teaching practices of the Mentor teachers, as well as their working relationships with the prospective teachers. I had worked shoulder to shoulder with the Mentors, as we initiated and developed an innovative SPDS during the previous 2 years. I had personally visited each Mentor’s classroom numerous times during the school year, and for several years prior to the study. The Mentors and I had many discussions about reforms and the realities of teaching science in actual classrooms, during formal science department meetings, in the school hallways, and in informal settings. Further, the beliefs and knowledge of the Mentor teachers, as well as their teaching practices, were documented and systematically examined (Kreamer, 2003; Crawford & Kreamer, 2003).

One question driving this study was, in what ways did the mentor teachers’ views of teaching science appear to support or constrain these prospective teachers’ intentions and abilities to teach science as inquiry? The Mentors’ beliefs and preferred instructional approaches certainly influenced some of the prospective teachers’ willingness to take risks in creating inquiry-based lessons. In the case in which a Mentor’s teaching style was very structured, even rigid, Helen rarely attempted an inquiry-based lesson. Helen reported that her reasons included her Mentor’s lecture-driven style of teaching, and her own perceived rigidity of the district science curriculum. Other prospective teachers echoed Helen’s reserved position on trying out inquiry-based instruction.

Yet, a Mentor’s openness or reluctance to allow a prospective teacher to try out new approaches did not fully explain the differentially enacted levels of inquiry. Related to the question, ‘‘to what extent did these prospective teachers articulate understandings of teaching science as inquiry?’’ there was evidence that some simply could not articulate what it means to teach science as inquiry. Disturbingly to me, as the university faculty member, several prospective teachers seemed to lack a clear idea of how to enact teaching science as inquiry in their classroom. Not knowing how to use inquiry-based strategies was a fact for some of the interns, despite the university’s emphasis on inquiry throughout the year.

When addressing another research question, ‘‘what were these prospective teachers’ beliefs of teaching science?’’ it became apparent that beliefs about teaching science as inquiry played a critical part in decisions about planning instruction. In fact, there was evidence that a prospective teacher’s set of beliefs about pedagogy, schools, student learning, and the nature of scientific inquiry may have been the overriding factor influencing choice and eventual success in teaching science as inquiry. The five prospective teachers held complex and sometimes, conflicting beliefs. This finding reinforces those of other researchers (Bryan, 2003; Wallace & Kang, 2004) in which teachers have different sets of beliefs that guide their instructional decisions. Practicing teachers studied by Wallace and Kang (2004), all interested in using inquiry-based instruction, held competing belief sets. One constraining set of beliefs arose from the school culture. In the present study some of the prospective teachers believed that the very nature of the typical high school learner precluded a teacher’s use of inquiry. Representative comments included: ‘‘it does not work with my kids,’’ ‘‘they are concerned about their grades,’’ ‘‘they are lazy,’’ and ‘‘they just want to get through it.’’ There was clear evidence that at least some of the prospective teachers developed beliefs that inquiry-based approaches were generally inappropriate for their high school students. Thus, their set of beliefs about the nature of students, gained from actual practice during the school year, likely constrained these prospective teachers’ intentions to teach science as inquiry. These findings align with previous literature, which attributes teacher beliefs to episodes in and out of classrooms (Nespor, 1987). Some prospective teachers became disillusioned with teaching science as inquiry during the course of the year, aligned with findings by Luft, Roehrig, and Patterson (2003) that novice teachers’ beliefs and practice are changeable.

Similar to the elementary student teacher in Bryan's (2003) study, there was tension between having a vision of teaching science as inquiry, and holding contradictory beliefs about schools, the role of the teacher, and the role of the student. Josephine (Biology) and Helen (Earth Science) articulated the most guarded views and reservations about teaching science as inquiry. These two were reluctant to involve their students in framing their own questions or in formulating explanations. These findings support those of McGinnis et al. (2004) pointing to novice teachers encountering affordances and constraints arising from the school culture, and these constraints can dissuade teachers from successfully carrying out reformed-based teaching strategies.

However, it is important to note that Josephine and Helen's mentors were positioned at opposite ends of the spectrum of openness to allowing their prospective teachers to try new strategies. For example, Josephine's mentor was very receptive to allowing her to try out innovative approaches. Josephine received encouragement and pedagogical support. Yet, by the end of the year, Josephine preferred a traditional style of teacher-directed instruction, interspersed with selected hands-on activities. A prospective teacher needs a robust understanding of scientific inquiry and well-articulated beliefs to overcome constraints arising from the culture of the high school.

One alternative explanation for why some prospective teachers attempted to teach science as inquiry, and others did not, is level of subject matter expertise. Helen struggled with the subject matter of physics, as well as earth science. When planning her lessons Helen admitted, for much of the time, she was in survival mode. In contrast, Jason, an Honors College student in physics, had a depth of knowledge of physics from which to draw upon. The five prospective teachers' differential practices of teaching science as inquiry, might be explained by their different epistemological views (knowledge about their discipline), rather than simply their views of learning or their views of subject matter (Prawat, 1992).

Limitations of the Study

A methodological issue is the inherent messiness of exploring teachers' beliefs and knowledge in the context of actual classroom experiences. One cannot know all of the many extenuating circumstances and variables that might contribute to a teacher's decision making about curricula and/or teaching strategies. Classrooms are complex. The nature of a typical student in an AP Physics class can be very different from the nature of students in a heterogeneously grouped earth science class. In addition, teachers have years of experience, which have shaped their views in ways that a researcher may never fully understand. There are many variables. We can only strive to develop a body of evidence to support explanations of why certain prospective teachers choose to try to use inquiry-based approaches, and why others do not.

Conclusions

Evidence from this study strongly suggests the most critical factor influencing a prospective teacher's intentions and abilities to teach science as inquiry, is the prospective teachers' complex set of personal beliefs about teaching and views of science. A prospective teacher's personal view of teaching science as inquiry, comprised of his or her knowledge of scientific inquiry and of inquiry-based pedagogy and his or her beliefs of teaching and learning, is a strong predictor of a prospective teacher's actual practice of teaching science. On the surface, this statement may seem to conflict with previous research, citing that a teacher's conception of the nature of science does not necessarily influence classroom practice (Lederman, 1999). However, in the present study the two prospective teachers exhibiting the firmest views of engaging students in inquiry were able to enact those views, to a certain extent, in their practice. This relationship between beliefs and practice aligns with the findings of Luft et al. (2003), in a study of beginning secondary science teachers. A prospective teacher's set of beliefs, including his or her epistemological assumptions about science (Prawat, 1992) may serve as the driving force that propels a novice teacher towards designing innovative instruction, in the face of cultural obstacles (i.e., resistant students, reluctant mentors, district curriculum).

Because the demands of orchestrating this kind of teaching are high, this calls into question the feasibility of novice teachers to carry out this kind of instruction. It is evident that some of the prospective teachers in this study did not feel confident and/or enthusiastic about engaging their students in aspects of inquiry. Many did not feel fully equipped with enough of an arsenal of strategies and techniques to successfully conduct inquiry-based instruction. Scaffolding students in framing questions, grappling with data, creating explanations, and critiquing explanations (including others' explanations in a public forum), are important components associated with teaching science as inquiry; and prospective teachers need to understand and practice these strategies, before they can feel an honest confidence in their ability to carry out this kind of reform-based instruction.

It is imperative that teacher educators understand how to best support and encourage teachers in learning how to engage students in learning about scientific habits of mind and the nature of scientific inquiry. To track and document progress, it is important to examine a teacher's conception of inquiry (his or her understandings of the nature of scientific work and of the pedagogy of engaging children in inquiry) in conjunction with his or her philosophy of teaching and learning science. This study raises questions about how one can effectively track a teacher's evolving knowledge and set of beliefs about teaching science as inquiry, in a practical sense.

In this paper, I present an argument for the importance of researchers examining teachers' knowledge and beliefs in the rough and tumble of practice. It is not enough to assess prospective teachers' beliefs, devoid of the context of practice. This involves the difficult task of uncovering views of teachers, as well as determining how teachers enact their philosophies in actual science classrooms. In interpreting the views of these five prospective teachers as they enacted teaching as inquiry over the course of a year, it was helpful to use the construct of situated cognition (Brown et al., 1989), in that all knowledge is a product of the situations in which it is produced. In this study the beliefs and actions of the Mentors most certainly influenced the prospective teachers' willingness to engage their students in learning about scientific inquiry. A novice teacher lacking confidence to stand in front of a classroom of students may certainly be cautious in using an inquiry-based approach, when that approach is in direct contrast to one used by the Mentor.

Teacher educators may model the design of inquiry-based lessons in theoretically steeped methods courses; but these findings suggest that modeling is clearly not enough. The study of teachers' beliefs of teaching and learning cannot be isolated from the real world of classroom practice. As in the findings of Richardson, Anders, Tidwell, and Lloyd (1991) a teacher's beliefs cannot be expected to change devoid of practice.

Finally, this study suggests that educational researchers consider a shift from doing research *about* teachers to doing more research *with* teachers. As the prospective teachers' actions and beliefs were studied, each member of the research team acted in the role of coach, facilitator, co-planner, and co-learner. Researchers, practicing teachers, novice teachers, university instructors, and supervisors, all participated in discussions and interactions about what it means to teach using scientific inquiry, how to teach about scientific inquiry, and the constraints associated with teaching science as inquiry. Each participant contributed towards constructing the cognitive apprenticeship, which guided each prospective teacher's evolution as a teacher.

Facilitating teachers in changing their beliefs, especially intuitively reasonable ones, is a difficult proposition (Prawat, 1992). Teaching science as inquiry must be both feasible and viable in the mind of the teacher. Teachers need to see that things can work, that it is possible to carry out inquiry-based instruction in actual classrooms; and be able to evaluate their current beliefs for effectiveness (e.g., to see that children may not develop understandings of scientific inquiry and of scientific concepts by a simple transmission approach). This study raises questions about providing ways to assess students in varying settings, which can inform teachers about the effectiveness and appropriateness of using inquiry-based approaches.

Implications for Science Education

Responsibility for enhancing prospective teachers' understandings of scientific inquiry, abilities regarding the nature of scientific inquiry, and abilities to design and carry out reform-based instruction, all fall squarely upon the shoulders of the science teacher educator. It should be recognized that an advocate for reform-based teaching strategies (such as inquiry-based teaching) is a proponent of change. And change is seldom achieved without cost. The status quo of education, the direct teaching method and its permutations, has a great deal of inertia. Most educators are comfortable with this approach; many assessment tools are still addressed by this method; and, it is what our student teachers have observed and experienced. Bybee concluded that, "most evidence indicates that science teaching is not now, and never has been, in any significant way, centered in inquiry whether as content or as a technique" (Bybee, 2000, p42). Asking our newest teachers to incorporate inquiry-based teaching strategies into their practice is not done without understanding that extra energy will have to be expended and choices defended, before they can expect to see many positive results of the new strategy.

It should be expected that prospective teachers articulate a personal philosophy of learning and of teaching science (Crawford & Lunetta, 2002). In these philosophies, prospective teachers should make explicit connections between an inquiry process, their understanding of how people learn science, and their teaching practice. In other words, a prospective teacher should develop and write a philosophy that is backed by evidence and supported by his or her personal experiences. Such a philosophy needs to be dynamic, with the expectation that it will continue to evolve to incorporate the teacher's further educational experiences.

We do not ask our novice teachers to embrace reform methods on faith alone or because their science educator recommends them. Rather, we need to enlist our new colleagues in education in the struggle for change. Theirs should be a conscious choice, knowing the difficulties, but valuing the rewards. They need to be able to demonstrate and document, both to themselves and their critics, why an inquiry-approach is a better choice for some science instruction. And they need to feel free to guide the evolution of their philosophy with confidence.

As advocated by Keys and Bryan (2001), more research is needed on teacher-designed approaches to inquiry, specifically, in high school classrooms, which are often constrained by high-stakes testing and fixed schedules. Eliciting the voices of teachers in the context of their practice offers a powerful vehicle for synergy, collaboration, and creation of an environment in which change is possible.

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Appendix A

Interview Protocol for Interns

1. Tell me about your background and pre-service training.
2. Tell me about your experiences with science courses in middle-high school and college. Lab experiences? Long-term investigations?
3. Why should we teach science? What are your broad goals for teaching science?
4. How do you believe students learn science best?
5. If I ask you to give me a metaphor for "scientific inquiry" what would you tell me? Explain how this relates to what scientists do (inquiry)?
6. Current reform in science education calls for teaching "science as inquiry." Tell me, how would you teach science as inquiry? What practices, in your view, account for teaching science as inquiry? What are your views of teaching science as inquiry?
7. How well do you think your pre-service teacher education courses (both science and science education) prepared you? What are some things you feel well prepared to do; things you feel you are not very prepared?
8. Describe for me how you would teach a unit of your choice, from beginning to the end, in terms of the sequence of events that would occur? Lab at the end, beginning? Why? Think of an example of a unit. Tell me what you would teach first, second, last.
9. How much freedom would you give your students to investigate problems of their own choosing?
10. Is there anything you would like to add, related to anything that we talked about today?

Appendix B

Scoring Guide for Content Analysis of Prospective Teachers' Inquiry-based Units based on Table 2–6. Essential Features of Classroom Inquiry and Their Variations (NRC) (2000) *Inquiry and the National Science Education Standards*, p 29.

Level	Elements of Teaching Science as Inquiry
	Learner engages in scientifically oriented questions
3	Learner poses a question
2	Learner selects among questions, poses new questions or learner sharpens or clarifies question provided by teacher, materials, or other source
1	Learner engages in question provided by teacher, materials, or other source
	Learner gives priority to evidence in responding to questions
3	Learner determines what constitutes evidence and collects it
2	Learner directed to collect certain data or learner given data and asked to analyze
1	Learner given data and told how to analyze
	Learner formulates explanations from evidence
3	Learner formulates explanations after summarizing evidence
2	Learner guided in process of formulating explanations from evidence or learner given possible ways to use evidence to formulate explanation
1	Learner provided with evidence and how to use evidence to formulate explanation
	Learner connects explanations to scientific knowledge
3	Learner independently examines other resources and forms the links to explanations
2	Learner directed toward areas and sources of scientific knowledge
1	Learner given possible connections
	Learner communicates and justifies explanations
3	Learner forms reasonable and logical argument to communicate explanations
2	Learner coached in development of communication or learner provided broad guidelines to use sharpen communication
1	Learner given steps and procedures for communication

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