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ABSTRACT

"Inquiry" is the enterprise by which scientists generate theory. It is also a broadly-applied label for instructional approaches in which teachers and students emulate the activity of scientists in order to generate personal knowledge of natural phenomena and to come to understand the canons of disciplinary knowledge-building. Despite the ubiquity of the term "inquiry" in science education literature, little is known about how pre-service teachers conceptualize inquiry, how these conceptions are formed and reinforced, how they relate to the actual work done by scientists, and how teachers' ideas about inquiry are translated into classroom practice. This is the third in a series of studies that have examined these issues within the context of pre-service education. This is a multi-case study in which 12 pre-service secondary science teachers developed their own empirical investigations from formulating questions to defending results in front of peers. The participants maintained journals throughout this experience, were then interviewed, and then followed into their 9 week teaching practicum. Findings indicate that there were implicit cultural models that participants used to make sense of their inquiry, and that these models guided the conduct and reflections of participants in the study. Some of the rules underlying these cultural models were congruent with a limited view of science inquiry, however, the most consistently implied rules across participants were misrepresentations of some of the most fundamental aspects of scientific inquiry. Another theme that came to light was a relationship between participants' struggles with their own investigations and, the emergence of a classroom model of inquiry that emphasized the need to "help" their future students engage in this enterprise. Participants identified three general strategies for instructional support: direct instruction on aspects of inquiry, adding more structure to the inquiry process, and, using scaffolding techniques centered on sense-making activities and peer dialogue as a way to learn. Finally, as was true in the first two studies in this series, the participants with significant, long-term research experiences and science content background were most likely actually to use inquiry in their own classrooms. Field Supervisor Observation Instrument and Thinking about the Nature of Science (NOS) exercise are appended. (Contains 50 references and 3 figures.) (Author/MM)

The Reproduction of Cultural Models of "Inquiry" by Pre-service Science Teachers: An Examination of Thought and Action

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Abstract

"Inquiry" is the enterprise by which scientists generate theory. It is also a broadly-applied label for instructional approaches in which teachers and students emulate the activity of scientists in order to generate personal knowledge of natural phenomena and to come to understand the canons of disciplinary knowledge-building. Despite the ubiquity of the term "inquiry" in science education literature, little is known about how pre-service teachers conceptualize inquiry, how these conceptions are formed and reinforced, how they relate to the actual work done by scientists, and how teachers' ideas about inquiry are translated into classroom practice.

This is the third in a series of studies that have examined these issues within the context of pre-service education. This is a multi-case study in which twelve pre-service secondary science teachers developed their own empirical investigations— from formulating questions to defending results in front of peers. The participants maintained journals throughout this experience, were then interviewed, and then followed into their 9-week teaching practicum.

Findings indicate that there were implicit *cultural models* that participants used to make sense of their inquiry, and that these models guided the conduct and reflections of participants in the study. Some of the rules underlying these cultural models were congruent with a *limited view* of science inquiry, however, the most consistently implied rules across participants were *misrepresentations* of some of the most fundamental aspects of scientific inquiry. Another theme that came to light was a relationship between participants' struggles with their own investigations and, the emergence of a classroom model of inquiry that emphasized the need to "help" their future students engage in this enterprise. Participants identified three general strategies for instructional support: direct instruction on aspects of inquiry, adding more structure to the inquiry process, and, using scaffolding techniques centered on sense-making activities and peer dialogue as a way to learn. Finally, as was true in the first two studies in this series, the participants with significant, long-term research experiences and science content background were most likely to actually use inquiry in their own classrooms.

Background

Inquiry Instruction in Science Classrooms

"Authentic science" activities for K-12 students is a priority of the American educational agenda (see AAAS, 1993; NRC, 1994; NSTA, 1995). The National Committee on Science Education Standards and Assessment has asserted that "*...inquiry into authentic questions generated from students' experiences is a central strategy of teaching science*" (1996, p. 21), and, that students should "*engage in aspects of inquiry as they learn the scientific way of knowing the natural world, but they should also develop the* *capacity to conduct complete inquiries.*" For a science student, developing one's own question and the means to resolve the question suggests an inquiry experience that is profoundly different from the far more common tasks of science schooling which consist of answering questions prescribed in the curriculum using methods also preordained in the curriculum or by the classroom teacher.

Inquiry, in any form, has not yet become a characteristic of science classroom practice (Wells, 1995). In classrooms where it does take place, confirmatory exercises and structured inquiries are far more common than guided or independent inquiries (Tobin, Tippins & Gallard, 1994). In a recent U.S. Department of Education report on student work and teacher practices in American schools, 69% of 12th graders surveyed indicated that they had "never" or "hardly ever" designed and carried out their own investigation. Thirty-seven and thirty-two percent of students surveyed in grades eight and twelve respectively reported that they did not "conduct science projects or investigations that took a week or more" (U.S. Department of Education, 1999). There may be several reasons for the lack of extended inquiry experiences: most science teachers view inquiry as difficult to manage, many teachers believe inquiry instruction is possible only with above average students, and science teachers may be confused about what constitutes inquiry (Blumenfeld, Krajcik, Marx, & Soloway, 1994; Hodson, 1988; Welch, Klopfer, Aikenhead, & Robinson, 1981).

One potential influence on the lack of opportunity for authentic investigations is teachers' conceptions of the nature of inquiry. Often, teachers hold positivistic views of science (Pomeroy, 1993) and many believe in a universal stepwise procedure— "The Scientific Method"— for doing science, thus dismissing the complex, creative, and imaginative nature of the scientific endeavor (Abd-El-Khalick & BouJaoude, 1997; Lederman, 1992). Classroom case studies indicate that teachers form individualized conceptions of inquiry and employ these for science teaching in ways that may not align with the conceptions of education reformers (Carnes, 1997; Crawford, 1998; Flick, 1995; Fradd & Lee, 1999). It is likely that there are multiple causes for these conceptions, many originating in previous science learning situations. The following section explores some of the experiences that contribute to conceptions of inquiry science for pre-service teachers.

Inquiry Experiences and Pre-service Teachers

Teachers themselves are products of traditional K-12 schooling. As learners, they are often exposed to teacher-centered instruction, fact-based subject matter, and drill and practice (Russell, 1993). These experiences furnish prospective teachers with mental models of instruction which they use to imagine lessons in their own classrooms, develop innovations, and anticipate learning outcomes (Kennison, 1990). Teachers, as some researchers have noted, are less likely to be guided by instructional theories than by familiar images of what is "proper and possible" in classroom settings (Russell, 1993; Zeichner & Tabachnick, 1981).

Much of what prospective teachers learn about inquiry and about teaching comes from their experiences as undergraduates. As with pre-college schooling, instructors in higher education not only teach the content of their courses, but they also model teaching practices and strategies for prospective teachers in their classes (Grossman, Wilson, & Shulman, 1989). What then, is the model of inquiry that pre-service science teachers are exposed to in undergraduate science classes? Generally, they are not unlike the confirmatory laboratory experiences found in high school. Trumbull and Kerr (1993), for example, found that much of what went on in a typical undergraduate biology laboratory class was highly scripted and tightly controlled— students were given the questions to answer and the methods to answer them. Lab assistants in this study reported that because of this approach, students lacked the focus necessary to carry out the inquiry or even understand the reasons for collecting data.

In addition to the problem of being subjected to models of highly-structured inquiry, pre-service teachers are rarely exposed to discussions about science as a discipline at the college level and do not participate in discussion of how new knowledge is brought into the field (Bowen & Roth, 1998). Schwab (1978) defined these areas of understanding as the knowledge of syntactic structures. The syntactic structures of a discipline are the canons of evidence used by members of the disciplinary community to guide inquiry in the field. For teachers familiar with the syntactic structures of science, biology class for example is not just about memorizing phyla, it includes discussions and activities aimed at developing an understanding of the methods of biological inquiry. However, teachers who lack knowledge of the syntactic structure of their discipline are less able to incorporate that aspect of science into their curriculum (Grossman, Wilson, & Shulman, 1989).

There have been calls to integrate more authentic inquiry experiences into not only undergraduate science courses but into teacher education courses as well (Tamir, 1983; van Zee, Lay & Roberts, 2000; Welch, et al., 1981). The studies that have been done on inquiry in teacher education programs indicate that pre-service teachers may need such experiences to develop their understandings of authentic scientific investigations. In a study of 25 preservice teachers with science degrees who were asked to conduct independent inquiry on an ecology topic, Roth (1999) found that they had considerable trouble creating research questions. Many developed questions that were correlational in nature, but believed that they could use the results as proof of cause-and-effect relationships. Several of the students were unable to operationalize variables in a way that would allow unambiguous measurements. Almost half of the final reports contained claims that either did not relate to the original question or did not logically extend from the data collected.

In a study conducted with an elementary science methods class, Shapiro (1996) found that 90% of her students had never experienced science as an investigation, and most of those who had, did so in school science fairs. She asked students to work with partners to answer questions of their own design. Over a seven-week period devoted to this investigation, students kept journals describing their efforts at posing questions, developing approaches to problem-solving, and interpreting their findings. Most of the participants struggled with the formulation of a question, with investigative design, and with data collection; however these same individuals later testified to the intellectual satisfaction of successfully creating their own questions and testing them. Students with the least extensive backgrounds in science made the greatest changes in their conceptions about the nature of science and scientific thinking.

Clearly there are a number of experiences that can influence pre-service teachers' conceptions of and beliefs about inquiry. They range from their own experiences as students, to their work in laboratory settings at the college level, to their coursework in teacher education. Many of these experiences are as likely to distort their image of inquiry as they are to enhance it, and more must be done in teacher education programs to help pre-service teachers develop realistic understandings of authentic scientific practice.

Reflection on Inquiry Experiences

Involving pre-service teachers in inquiry experiences may not be enough to develop their conceptions of inquiry or their ability to use it in the classroom. For example, in two previous studies on inquiry projects with pre-service science teachers, Windschitl (2001, in press) found that the project *refined the inquiry conceptions of those participants who already had more sophisticated understandings of scientific investigations*. Those participants with simplistic notions of inquiry were less likely to change their views. Perhaps most importantly, the participants who eventually used inquiry during their student teaching were not those who had more authentic views of inquiry or reflected most deeply about their own inquiry projects, *rather, they were individuals who had significant undergraduate or career experiences with authentic science research.*

Using the Idea of "Cultural Models" for Theory-building About Inquiry

This study's analysis of pre-service teachers understandings of inquiry is based largely on the theoretical and methodological tools of *cultural models* and *situated meanings*, articulated by James Gee (1999). Both *cultural models* and *situated meanings* involve ways of looking at how speakers and writers give language meaning within specific situations.

Words have multiple and constantly changing meanings created for and adapted to specific contexts of use. At the same time, the meanings of words are integrally linked to particular groups in ways that transcend individual minds. When we use language, we both create the contexts (making things meaningful in certain ways and not others) and adapt our language to these ongoing contexts, which often get created in relatively similar ways from time to time and usually stay in existence, due to people's interactional work. This is the notion of *reflexivity* in language (Duranti & Goodwin, 1992; Hanks, 1996; Gumperz & Levinson, 1996) — essentially it suggests that there is reciprocity between language and "reality." Language simultaneously reflects reality ("the way things are") and constructs the meaning of it (shapes situations through its use).

With regard to situated meanings, humans recognize certain patterns in their sociocultural experience of the world. In the context of a science teacher in a classroom saying something like "We're going to do an inquiry activity this week" to his students, the taken meaning of "inquiry" is likely very different from the meaning of "inquiry" when uttered by a detective trying to solve a murder, a historian trying to understand the rise of democracies in the 20th century, a poet trying to understand herself through an invented character, or a person asking for directory assistance (all are "inquiries" of one sort or another). Within the context of the science classroom, "inquiry" is likely to be associated with activities such as "working with measurement tools", "writing in a lab book", "graphing data", or "presenting results."

There is more to meaning than patterns, however. Words also involve implicit explanations of these patterns (Anglin, 1977: Kiel, 1979, 1989). The patterns are required for people to make sense within some kind of cause-effect model or "theory" of a domain. Everyday, people form, transform, and deal with such "theories." However, everyday people's "explanations", "models", or "theories" are very often largely unconscious, or at least not easily articulated in any very full fashion, and are often incomplete. Furthermore, these cultural models reside in people's heads (different pieces for different people) while other fragments reside in the practices and settings of cultural groups. They are often shared across people, various texts, other media, and various social and educational practices. Because these theories are rooted in the practice of socioculturally defined groups of people, they are often referred to as *cultural models* (D'Andrade, 1995; D'Andrade & Strauss, 1992, Holland & Quinn, 1987, Shore, 1996).

Within the science education community, the idea of "inquiry" has been the subject of a number of cultural models, albeit often incoherent in their particulars and across groups of scientists, researchers, and practitioners. Inquiry has been associated with a wide range of intellectual activities, including hypothesis testing, practical problem-solving, modeling, and engaging in Socratic dialogue. It has been equated with hand-on activities, discovery learning, and projects.

Of all these instantiations, "hypothesis testing" is one of the most widespread cultural models of inquiry. It is commonly portrayed by textbooks as a linear process and referred to as "The Scientific Method." These are both misrepresentations. First, the process of hypothesis testing in science is not a linear one in which each step is a discrete event whose parameters are considered only after the previous step is complete. In authentic scientific practice, multiple steps or phases are often considered in relation to one another at the outset of the investigation. The particulars of hypothesis generation, data collection, and analysis are mutually interdependent considerations. Second, with regard to "The Scientific Method," analyses of practice in scientific communities have shown that there is no universal method, and that science inquiry can take a variety of forms (Alters, 1997; Knorr-Cetina, 1999; McGinn & Roth, 1999). Procedurally, some scientists do formulate and then test hypotheses; other scientists, however, construct their hypotheses only after data analysis, and still other scientists, such as field biologists, astronomers, or anatomists, conduct descriptive research in which hypotheses may not be explicitly tested (Latour, 1987).

Using this conceptual framework we may ask, "What are the relationships (or discontinuities) between cultural models of inquiry that scientists use, and those understood by science teachers?" Further, "How do these cultural models for inquiry translate into visions of classroom practice?" The "explanatory theory" that goes with "inquiry" has to do with things like the idea that human conduct inquiries in order to "find something out," but there are different forms of inquiry that are more or less scripted, more or less social, directed to different ends and enacted in different situations. Different "theories" of inquiry then, encapsulate viewpoints on who conducts inquiry, how it unfolds, and for what purposes. The idea of "inquiry" clearly differs between psychotherapists, bank examiners, and architects. But it may also vary among scientists in various domains, science teachers, and students in a science classroom—and have significant pedagogical implications.

To begin to answer some of these questions, we must think of situated meanings and cultural models as tools that help us understand how people engage in "building tasks" (Gee, 1999). Building tasks involve using language to construe a situation in certain ways and not in others (talking about "inquiry" in a middle school science classroom, for example). They are carried out in negotiation and collaboration with others in interaction. Even when individuals engage in independent activities, Gee points out, these building tasks are carried out in negotiation with relevant texts we have read, with sociocultural knowledge we bring to the activity (images, analogies, stories), and with discussions we have had with other people. These building tasks are simultaneously cognitive achievements, interactional achievements, and inter-textual achievements. The particular tasks relevant to this study are:

- World-building—assembling situated meaning about what is here and now (taken as) "reality," what is here and now taken as present/absent, concrete, abstract, "real or unreal," probable, possible, or impossible.
- Activity-building—assembling situated meanings about what activity or activities are going on, composed of what specific actions.
- Connection-building—making assumptions about how the past and future of interactions are connected to the present moment and to each other.

These theoretical building tasks help frame questions of interest in this study.

Purpose of Study

This study has two related but distinct parts. *Part I* is an examination of how pre-service teachers both use and re-create cultural models of "inquiry" within independent investigative experiences. The research questions in this section are:

1) What cultural models are relevant to these students as they construct and interpret their own inquiry experiences?
2) What cultural models and networks of models seem to be at play in connecting and integrating these situated meanings to each other?
3) What institutions and/or discourses are being reproduced in this situation and how are they being stabilized or transformed in the act?

Part II of the study attempts to identify links between pre-service teachers' conceptions of inquiry, their past inquiry/research experiences, and the use of inquiry in their own classrooms. One question was examined:

4) What conceptions of inquiry and previous investigative experiences are linked with pre-service teachers' use of inquiry in the classroom?

Context

Participants

The 12 participants in this study were students in a teacher education program at a public university in the northwest United States, all enrolled in a secondary science methods course. The teacher education program at this institution is relatively small, and is dedicated to producing graduates who will assume leadership roles in their schools as well as become exemplary classroom teachers. Students enter the program from a variety of undergraduate institutions; about one-third of the members of each class complete their baccalaureates in other regions of the country. All candidates must enter with a bachelors degree in some area of science and they graduate with a Masters in Teaching degree. Many of these pre-service teachers have prior work experience in science or technology fields. The methods students in the current study were part of a larger secondary cohort of approximately 65 students who took most courses together but attended methods classes in their subject-specific groups.

The methods course included explorations of the nature of science, goals and objectives in teaching, lesson planning, unit planning, laboratory work, inquiry, problem-based instruction, conceptual change teaching, constructivist classroom culture, technology in science teaching, curriculum, and safety. The course was two quarters in length and was taught by the author. The author is a former secondary science teacher with 12 years of experience in inquiry-based teaching.

The Inquiry Project

The first week of the course was designed to help students develop a foundational understanding of science as a way of knowing the world and finding out what scientists actually do. During the second week of the fall quarter, the instructor initiated a discussion about inquiry and about the role of various kinds of investigations in generating new knowledge. This topic laid the groundwork for later discussions around what it means to be science-literate and how the methods students could use this background to develop goals and objectives for instruction.

During these discussions a number of different perspectives emerged from the students about "The Scientific Method" as a systematic way to generate knowledge. Most students supported the notion that the scientific method is not a linear process by which researchers unproblematically move from observations to questions to hypotheses, and so on. Most students, however, were unable to articulate a coherent model of inquiry, having few relevant inquiry experiences of their own to draw upon.

The lack of inquiry experiences has been a consistent problem in this particular course. For the past four years, methods students in this course have been asked whether they have, in any science class (K-16), generated their own question for investigation and means to resolve the question. Only about 20% of these pre-service teachers had ever conducted independent inquiry— at any level of science education. And of this 20%, all reported that they engaged in only one or two such inquiry experiences.

In response to this perennial lack of research experience, methods students in this class were asked to engage in an independent inquiry as a course project. The topic of the inquiries had to be related to the theme of "pollution." Students were encouraged to spend a week simply observing their neighborhood environments and considering questions that came to mind. The questions could be about chemicals in the environment, animal activities, weather phenomena, noise, technology, or other pollution-related science topic. Students were then asked to design an investigation, collect and analyze their own data, and defend the results of their inquiry to the class in a formal presentation. Students were given eight weeks to complete their inquiry. The students' research projects encompassed a wide range of interests. They investigated, for example, the sound buffering capabilities of trees, dispersal patterns of smoke in bars, acid rain, and the effects of oil pollution on sea urchin reproduction.

The Reflective Journal

In order to capture students' ideas that were generated throughout the inquiry and make these ideas explicit objects of reflection, they were asked to maintain a journal in which they recorded the details of their inquiry. The journals eventually contained a range of written reflections, including not only the straightforward reporting of investigative procedures, but also the confusion, second thoughts, and false starts associated with independent inquiry. In addition to recording these thoughts, there was also a parallel record maintained. Each time they made journal entries about their inquiry project they also described how these experiences were informing their thinking about inquiry experiences for their future students. In this sense, it was a dual journal, intended to stimulate "pedagogical thinking" (Fieman-Nemser & Buchmann, 1985) by connecting episodes of personal inquiry experiences with a developing framework for working with future students.

The journals, then, were more than records of events— they were tools for aiding reflection. Reflective thought involves an examination of one's beliefs and the assumptions/aims that construct them in relation to ideas and practices in one's world (Jorgeston, 1994). Schon (1992) describes a specific type of reflection called a "conversation with the situation" in which the individual, as an inquirer, uses various tools and strategies to solve problems. In the act of using these resources, these tools and strategies "speak back" to the inquirer, prompting a transaction with the situation— a metaphorical conversation that is both a product of a person's thinking and that which shapes thinking. Being conscious of this conversation is important if one wants to understand how one is learning in a given situation as well as how to solve the problem at hand. The students' journals were intended to generate an on-going conversation with the inquiry situation. The journal was a way to externalize self-dialogue about the inquiry, which would normally be internal and poorly articulated, and to make this dialogue explicit to the student.

Complementary Course Experiences

A sequence of activities during the methods course (Figure 1) was designed to complement the independent inquiry experiences. During the second week of the quarter, students were introduced to the requirements of the inquiry project (described previously) and began their work on the project at the end of that week. Students were given the option of working with partners. There were eventually four partnerships and four students who worked individually.

From Weeks 2 through 9 of the course, a number of topics, not directly related to inquiry, were addressed. Students, however, were given 30 minutes every other class period during this time to discuss their ongoing inquiries in groups of six. These discussions often centered on the difficulties they were experiencing in generating researchable questions, problems in acquiring and using special equipment for their studies, and challenges they confronted in collecting data. These discussions were not structured by the instructor, but were intended to expose students to the wide range of inquiries underway by their peers and to the variety of challenges that arose during different investigations.

During Week 7, students were introduced to inquiry as a way of teaching. The methods students took on the roles of secondary school students as the class explored earthworm behavior. In small groups they observed earthworms and generated a number of questions. The instructor then demonstrated how a teacher could 1) scaffold learners' understandings of the difference between observations and inferences, 2) categorize questions that learners might have about earthworms, and 3) help learners transform some of these "everyday" questions into researchable questions. During the next class session, students agreed on one question upon which the entire class could conduct a brief study, and they brainstormed about the links between the question and the kinds of data one would need to answer the question. The class also explored how a teacher could scaffold learners' efforts to operationalize variables, design experiments, and standardize measurements. The class then conducted a whole-class guided inquiry on earthworm behavior. Part of Week 8 was devoted to discussions about how the guided inquiry with earthworms could act as a "springboard" for young learners to develop their own independent inquiries. Part of Week 8 was also devoted to explorations in the computer lab of how learners could organize and analyze data using various types of software and how one could generate meaningful representations of analyzed data.

During Week 9, the class explored together how a teacher could help students prepare for presentations to their peers, construct scientifically valid arguments based on data, and negotiate the kinds of questions students could ask their peers during presentations that would probe the investigations without promoting confrontations. During Week 10, students presented their inquiry results to their peers.

Week #	Selected Activities Complementing the Inquiry Project
1	• Panel discussion with two scientists and one teacher/researcher • Discussion "What does it mean to 'learn about' science, to 'learn science', and to 'do' science? "
2	• Students introduced to inquiry project
3	• Small group discussions about challenges of developing inquiry questions, assembling necessary materials, and collecting data
4	• Students in field (no class)
5	• Students in field (no class)
6	• Small group discussions about challenges in assembling necessary materials, collecting data, and analyzing data
7	• "Inquiry as a way of teaching" introduced as class topic • Exercises in scaffolding learners' understandings of observation vs. inference and the development of questions by learners • Whole-class guided inquiry on earthworm behavior (operationalizing variables, standardizing measurements, controlling variables)
8	• Discussions about using guided inquiry as springboard for independent inquiry • Using technology to analyze and represent data
9	• Exploring how to prepare learners to present inquiry and supporting arguments to peers
10	• Methods students present inquiry to their peers

Figure 1. Timeline of selected instructional activities complementing independent inquiry project during methods class.

Method

A multiple-case study approach was employed to make sense of the relationships between individuals' conceptions, plans, and actions regarding inquiry, and, to make comparisons across individuals (Miles & Huberman, 1994). During the inquiry, participants kept a journal in which they recorded their procedures, thoughts, and feelings about the inquiry process, and the implications of these experiences for the design of inquiry activities with their future students. Student completed a Nature of Science exercise in the second week of classes. After the final presentations at the end of the quarter, students were interviewed about their personal history with inquiry in science classes, and about experiences with inquiry/research in their professional careers, how they made sense of their own inquiry project, and how they translated their experiences into plans for using inquiry with their future students.

Finally, the researcher worked with two field supervisors who documented the use of inquiry-based teaching methods by the participants while they were in the field the following fall quarter. The field supervisors were former secondary science teachers with approximately ten years of experience each. One of the two supervisors observed each of the students multiple times each week for nine weeks at the beginning of the following school year. During this time, each participant had almost complete responsibility for designing and implementing the curriculum at their respective schools.

Data Sources

Primary data sources included participants' entries from their reflective journals, responses to a Nature of Science questionnaire, post-inquiry interviews, undergraduate transcripts, observations from two field supervisors who observed the participants for nine weeks in classrooms, and a post field-work interview with one participant. The Nature of Science instrument (see Appendix B) assessed students on 5 different dimensions: 1) science knowledge being subject to change over time, 2) types of questions that science can address, 3) whether scientific facts, theories, and principles are "discovered" (objectivist orientation) or "constructed" (constructivist orientation), 4) the role of logic and imagination in science, and 5) the existence of a "Scientific Method." Responses to each of these dimensions was elicited by creating a conversational exchange between two hypothetical individuals. One of these individuals offered the accepted view of the NOS and the other individual replied with comments indicating a naive view of the NOS. for example, with regard to science ideas being subject to change, the first individual comments:

> Changes in scientific knowledge are bound to happen because new observations can challenge our current theories. No matter how well one theory explains a set of observations, it's possible that another theory may fit just as well or better, or may explain a wider range of observations. It's like when scientists come up with new ways to describe what matter is made up of at the smallest, atomic levels or how the universe behaves—better theories always come along to replace the old.

To which the second individuals replies:

> Science knowledge does not change over time. Once good theories and explanations are created, they apply for all time. Otherwise, why would we bother to develop them? If there are competing theories, it's a matter of who is right and who is wrong.

With regard to participants' journals, they were coded based in part on analyses conducted in two previous studies. Codes included non-reflective designations such as 'recounting procedures", "experiencing problems", and "use of hypothesis, theory, or models to guide or interpret inquiry." They also included 1) reflective statements at varying levels—"connections to classroom inquiry with students" which was subdivided into "logistics of classroom inquiry", "intellectual challenges for students during inquiry", and "peer support during inquiry", 2) metacognitive statements and 3) reflection on the nature of science, which was subdivided into "what scientists do", "what science is", and statements about "scientific method."

Post-project interview protocols were constructed to probe for additional evidence in support of developing hypotheses. In particular, participants were asked about their inquiry experiences in their K-16 education and their experiences (if any) with science related research experiences in their careers. To assess participants' past experiences with inquiry, they were interviewed and asked to describe guided or independent inquiry experiences in high school or college. These ranged in scope from brief, structured classroom activities to long-term projects in which instructors mentored them through authentic problem-posing, research design, and data analysis. Inquiry experiences also included work outside of school. These ranged from working as a lab technician where they performed data collection and analysis protocols, to more involved membership on research teams where they participated in authentic problem-posing, research design, and data analysis.

From the interview data, participants were rated "High", "Modest", or "Low." Those who were rated "High" reported involvement in authentic research activities, either as undergraduates, graduate students, or in a career. This involvement included participation in framing questions, designing studies, and collecting and analyzing data. Those who were rated "Modest" reported two or three instances of independent or guided inquiry during their K-16 schooling and/or working in a science setting after graduation. This was work in science settings which was restricted to performing technical tasks (collecting and analyzing data, following protocols designed by others). These individuals were not involved in the posing of research questions or research design. Those who were rated "Low" reported no instances of independent or guided inquiry throughout their K-16 schooling, very few instances of structured inquiry during school and no work-related experiences related to research.

Finally, data was collected in the field by two supervisors who observed the student teachers in classrooms for nine weeks. The supervisors were asked to describe each participants' use of inquiry instruction in their classrooms. Specifically, the supervisors reported to what extent the student-teacher used structured, guided, or independent inquiry strategies during the quarter. During each visit, the field supervisors first determined the type of instructional activity or strategies employed. These could be discovery (brief activity to exemplify a scientific principle), a confirmatory laboratory, a lab skills exercise, discussion, lecture/direct instruction, worksheet/seatwork, or other activity. If the strategy involved some form of inquiry, the supervisor indicated the degree to which the inquiry was a teacher- or student-centered along five different dimensions. The supervisors used an observation instrument derived from a table in the National Research Council's publication: *Inquiry and the National Science Education Standards* (2000). The instrument table (2.6, p. 29) entitled "Essential Features of Classroom Inquiry and their Variations" (see Appendix A) describes five dimensions of classroom inquiry (e.g. "Learner engages in scientifically-oriented question"). Each of the dimensions has four increasingly learner-centered instantiations (ranging from, for example, "Learner poses a question" to "Learner engages in a question provided by teachers, materials, or some other source").

Findings

Part I

Beliefs About the Nature of Science

The *Nature of Science* (NOS) responses were highly similar across participants. For each of the 5 dimensions, all 12 participants wrote statements agreeing with the more sophisticated viewpoint. Similarities across participants even extended to the hypothetical dialogue questioning whether science required *logic or imagination*, where all 12 participants indicated that they believed *both* were important. The following response was typical:

> I agreed with James completely until I read the last sentence—I believe scientific arguments must conform to logic. However, in order to discover and explain events, scientists must be creative and willing to go beyond the scope of the known in an effort to explain the unknown.

There was one exception to the students taking the most sophisticated position on each of the dimensions on the NOS instrument. Several students indicated a belief in both objectivist and constructivist versions of scientific knowledge. Jenelle, for example, wrote:

> As humans, we have made simplified models of how the world works so that we can explain them in terms we can understand. As we have come to understand more and better, we can make more complex models about the world and still prove the world will follow our laws. The role of the scientist is to reveal what already exists, but also to find out connections, ways to make other people understand how the laws relate to each other and why.

Similarly, Joanne wrote:

> I agree with both Carrie and Maria. Like Carrie said, there are facts which scientists seek to reveal, but as Maria said, humans must find these truths. They must test hypotheses how they figure it might work best for these truths to be revealed, and they must explain the truths.

Beliefs about the NOS were so consistent within participants (each held authentic views on all five dimensions of the instrument) and across participants (all participants held similar views) that the only finding here is one that contextualizes the rest of the data (at the risk of redundancy): all participants held sophisticated views of science as a way of knowing the world.

Reproducing Limited Cultural Models of Inquiry

"Inquiry," as previously described, has a multitude of meanings, depending upon, among other things, the situations in which people use it and its construal with regard to available cultural models. From the journals and interview data in this study, "science inquiry" was taken to be more than "posing and finding the answer to a question"; there were additional implicit rules that seem to define inquiry and to have guided the conduct and reflections of participants in the study. For example, although some rules described by participants were *congruent with authentic science inquiry* ("inquiries involve questions, designing studies, and collecting and analyzing data"; "more than one data point is required for comparison groups"), other implicit rules seemed to represent a *limited view of scientific inquiry*:

- there is a scientific method, although it is not linear
- inquiry must be a comparison between two groups
- inquiries are synonymous with experiments

Furthermore, some of the most consistently implied rules across participants were *misrepresentations of some of the most fundamental aspects of scientific inquiry*:

- a "hypothesis" functions as a guess about an outcome, but is not necessarily part of a larger explanatory framework
- background knowledge may be used to give you ideas about what to study, but this knowledge is not in the form of a theory, explanation, or other model
- theory is something you might use at the end of the study to help explain results

The most serious shortcoming in the model of inquiry used/constructed by participants was the *absence of theory* in their investigations. This was evident in the journaling and interviews of almost all the participants. This was particularly interesting in light of the sophisticated views on all dimensions of the NOS instrument. Although participants appeared to hold sophisticated epistemological views with regard to the NOS, they did not make methodological connections that the investigations should be based on some explanatory premise and that the goal of inquiry is to refute, revise, or support scientific models.

The absence of theory, or even any background information to guide the development of questions was characterized by participants' brainstorming about questions and filtering them according to what was interesting, "doable," and novel. One participant, Nick, opened his journal with these lines:

> I am thinking about how noise pollution changes the environment. The effects of loud noise on plant growth/photosynthesis? What about setting up two plants each in the same window, playing music for a length of time each day and measuring changing heights, weights?

Another participant, Bria, wrote:

> ...we were thinking things up half the time that were measurable and then the other half of the time we were completely shifting our focus to what interested us about pollution in places near our house. Then we would filter these ideas back through the measurability factor and usually we'd have to start again.

Two days later in her journal, she added:

> We had an after class discussion expanding the banana concept. We went toward having the bananas in containers and exposing them to different types of air pollution. What about cigarette smoke? Fire smoke? And carbon monoxide even! We wanted to see what the air quality would do to the fruit.

Another participant, Jenelle, had an extensive knowledge of chemistry and may have had an implicit theory in mind, but her journal entry seemed to suggest a "try something and see what happens" orientation:

> We're just going to bubble [car] exhaust through water and see how acidic it gets over time.

One case in particular, Pamela, exemplified the tendency of participants to "leap" into empirical comparisons without considering any tentative explanatory framework to base the inquiry on. Pamela was a thoughtful and enthusiastic pre-service teacher. As an undergraduate she had worked for a professor involved in psychology experiments, but had only "run subjects through protocols" and had not been involved in development of research questions or the design of the investigations. She recounted only one other experience with research—that as an undergraduate in a zoology class. She "had to come up with something that had to do with animal physiology so we tested crayfish and different pH's in the water to see if it affected performance…we sort of timed them to see how long it took them to walk here and there under acidic and basic conditions." Pamela worked with a partner for her methods class inquiry. Over the first three days she recorded the following:

> — So I'm trying to focus on things that I am curious about and then see if a good question arises. How do detergents affect plant growth?
> — Another idea, how are plants affected by cigarette smoke?
> — Amanda and I decided to expand this question to how household cleaners like dish soap, Clorox, and floor cleaner affect plant growth if they are in the water. The main issue concerning this question is how you would measure it.

Pamela did not consider how or why detergents might affect plant growth and later journal entries did not indicate that she used theory or any explanatory framework to guide her thinking. She seemed focused on the limited inquiry model of "comparing conditions." Pamela moved on to considering her experimental set-up. She and her partner created four groups of plants (no control group): water with Clorox, floor cleaner, dish soap, and environmentally-safe kitchen cleaner. She placed four plants in each condition. Weeks later, Pamela was puzzled by the results of her experiment—all the seedlings looked healthy except for those that had been in the dish soap.

Despite not having any theory upon which to base her study, Pamela did make several important connections. A month into her inquiry, she wrote "I think I have gained a better understanding of what a good question is. In formulating a question you need to be thinking about how you would test it and how you would collect data that would support the question." Pamela had made a methodological connection between *the development of the question to the investigative design*, but did *not* make the equally important connections between *the question and an underlying explanatory framework* for the phenomena of interest. Her lack of connection with a theory seemed to be the reason for "being surprised" by the results. About six weeks into the experiment she found the unexpected: "The plants receiving the floor cleaner looked like they have received plant steroids! They are much bigger than the rest. The dish soap plants are the smallest."
She wondered in her journal whether or not her "hypotheses was correct", but her hypothesis was simply that there was going to be a significant difference between experimental groups. It was not until two months into the experiment that Pamela invoked an explanatory model: "It looks as if there is a significant difference between the floor cleaner and the control. I would hypothesize that there is nitrogen in the cleaner." This comment was made midway through her journal and never

revisited. She instead focused "inward" on her procedure, wrestling with how to analyze and draw conclusions from her data.

Her preoccupation with a kind of atheoretical "scientific method" was connected to a strictly stepwise model for inquiry and evidenced in further comments about her future students:

> Having done this project, I am now able to model what my thinking is. I could model to students the process of thinking about a question and help them design their own. This could be done with each step of the inquiry project: 1) Question, 2) Design experiment. 3) How to collect data, 4) How to analyze and determine what it means.

Determining "what it means" to Pamela meant being able to declare significant differences between groups, not using a model to explain why the results turned out the way they did. In an interview after the inquiries were completed, Pamela was asked if there was any difference between her inquiry and that of scientists. Her reply indicates the belief that scientists simply "come up with a question" as she had done, but that they had a *clearer plan of investigation* and that they were *more exacting in their measurements*.

> I think that it's pretty similar in the sense that you come up with a question and you have sort of an idea of how you're going to collect the data but that can change and you can get sort of new ideas and just be driving along going "Oh I can do that, maybe that would show me something"...I hope they'd probably put a little more thought behind, we kind of came up with question and we planted the plant before we really had a clear idea of exactly how we were going to test it and that's ? I think that maybe scientists probably have a clearer plan on how they're going to do it and that's probably a little bit more exact...

The idea that scientific inquiry differed from participants' inquiries only in scientists' exactitude and forethought in planning was consistently expressed in interviews. Returning again to Pamela, she was asked:

> I: Did you use any theory in developing your own inquiry or guiding your own inquiry, did you use anything?
>
> Pamela: What do you mean?
>
> I: Theory of, any scientific explanations.
>
> Pamela: I think just based, it was sort of based on the fact that if you add something, if plants basically respond to the nutrients that they receive in their growth and if you give you something that interferes with that or somehow, I don't know but basically that what they take in affects their growth so that was sort of, I don't know if that's a scientific theory but that's kind of what we based it on in terms of you know, feed them something and see if it affects how they grow.

During the course of the fall quarter, a conservative model of inquiry as a simple testing or comparison between groups seems to have been *reinforced by Pamela's visits to a local school* where students were "doing inquiry experiments." She wrote:

> Today at school the teacher had students start inquiry experiments...They first submitted three questions they could study using plants. The teacher then pointed them towards the ideas that was the most workable. It was really cool to see some of the ideas they came up with. Some students are feeding their plants Coke and others are testing the difference between real and fluorescent light. They are also using dyes and various types of soil—even gravel and sand. One group is testing the effects of

> music on plants. I was really surprised by the sophistication of their ideas—A lot of questions similar to the ones in our methods class. There was even a plant hanging upside down. It was very cool to see the inquiry method implemented.

Another participant, Joanne, was also confronted by traditional (conservative) models of inquiry in her field experiences. Joanne, however, saw an even more "reduced" model of inquiry—"cookbook" science in texts and noticed a reluctance on the part of classroom teachers to use inquiry.

> I wanted to know what the library offered in the way of suggestions for inquiry projects…the books they do have just give step-by-step instructions of what to do, what you should see, what the intended (correct) results mean. None of them are guides to inquiry projects. It bothers me that these books present science as a recipe for which correct results are expected. I asked the seventh grade teacher if they do any inquiry projects. She said that she used to spend some time on "kitchen science" but since the state mandates and district curriculum guidelines went into effect, she had no time for this. The teacher did hand out instructions for students to grow salt or sugar crystals.

In spite of this, even while participants understood the limitations of "cookbook" experiences for students, they continued to construct only a "marginally more authentic" inquiry model in their own investigations.

Supporting Future Students with Inquiry

Another theme that emerged from the data was a relationship between participants' ongoing struggles with their own investigations and the emergence of a classroom model of inquiry that focused on the need to "help" their own students engage in such an enterprise. Participants identified these general strategies for instructional support (ranging from more teacher-controlled to more student-centered):

1) providing direct instruction on procedures and skills used in inquiry (but interestingly, not on background content or the use of guiding theory),

2) adding more structure to the inquiry process (giving students a highly restricted number of topical options to choose from in designing their inquiry, fashioning research questions for them, requiring student proposals and approval by the teacher), and

3) using scaffolding techniques centered on sense-making activities by students and the use of peer dialogue as a way to learn.

Most participants mentioned at least two of these three general strategies.

An example of the relationship between participants experiencing challenges in their own inquiry and their subsequent re-vision of classroom inquiry is demonstrated by Amanda. Amanda had teamed with Pamela to do the plant experiments with the various cleaning solutions (mentioned previously). As Amanda, over time, felt increasingly challenged by her inquiry, she correspondingly wrote about more and more control being needed by a classroom teacher over such a process. She began by suggesting ways she might scaffold students' understanding of data collection and analysis:

> What type of qualitative data could we collect? What observations would prove useful? Similarly, what quantitative data would help us discern if the chemicals had an effect on the plants? This seems an area that a teacher could scaffold students through. If I wanted to help my students discover what data is relevant data, we could work on some sample problems in class. I could describe an experiment to my students and we could discuss what data answered the question being asked. For instance, if an experiment was designed to answer the question on whether light affects plant growth, does data collected on the soil pH answer the question being asked? This type of activity seems an excellent opportunity for discussion in a group

setting. Similarly, I could sit down with each group of students conducting independent inquiry and we could discuss what type of data they were collecting and I would have each group defend to me how the data will answer their question.

After completing the second week of her own inquiry, however, Amanda began expressing concern about her ability to use inquiry in her classroom.

I've been thinking a lot about independent inquiry and its feasibility in the classroom lately. I mentioned in a previous entry that students might have difficulty figuring out what data answers their questions, but I'm beginning to wonder about other areas of difficulty. I'm beginning to realize how easy it is for students to quickly become lost in science.

I wonder if all the areas of independent inquiry might cause trouble for students. I'm not trying to sound as if I don't want to do independent inquiry, because I most certainly do. What I'm wondering, is for my students, particularly in the middle school, if all areas might be problems? For instance, I see students having difficulty deciding what question to ask. Then forming a hypothesis relevant to the question, then deciding what type of data to collect, collecting data, avoiding confounds, analyzing data, etc. Would it really be feasible for a teacher to work closely with each group with a group of students to help them through each step?

I suppose I could have students turn in periodic write-ups of where they are in their experiments and I could gauge how they're doing from that, but I think it would be more beneficial for me to work individually with each group of students. Time constraints seem to make this difficult. I know I could scaffold students through asking questions and collecting data in general, but I'm not sure if middle school students would be able to make the connections.

Soon, Amanda began to *combine scaffolding with techniques of control*—a narrowing down of options to keep students from getting overwhelmed.

... I think the best way to do something like this with middle school students is to limit the number of topics they can conduct inquiry on, or to choose one topic for the students to conduct an experiment on. Then, we could as a class brainstorm a list of questions that could possibly be asked about the chosen topic. Then, once an approved list is established, the students could choose a question from the list and would then have to check their hypothesis with me. From here students would still design their own ways to collect data, but guidance seems to be the key with students, particularly middle school students.

The key, I've realized is just to not allow students too much lee-way so they don't get lost.

Not only does the project itself take time, but it also takes time to guide students through their thinking. It is becoming more and more clear to me that students cannot just be left alone to their own investigations, as we were. That would just be too frustrating to them, particularly in the middle school. I know that I will need to serve as a sort of tour guide for my students' projects.

Finally, Amanda differentiated "inquiry projects" from "inquiry activities" as a way to reduce the complexity of classroom inquiry for her and her students:

> I think the way to successfully incorporate this type of inquiry is not to teach major material this way, but rather through inquiry activities (activities that can be started and finished in a day or two). Inquiry projects that are lengthy and ongoing should be used to reinforce ideas or test students thinking.

Another participant, Joanne (who conducted an inquiry on the effects of cigarette smoke on plant growth), wrote about "narrowing down options" for her students, but she also emphasized peer support. She connected many of her own experiences with her peers in the methods class, with middle school students being helped by their classmates.

> I'm glad I got the chance to discuss my project with my peers. It really got me thinking about my methods and choices I have made so far. Students should definitely have the opportunity to discuss inquiry projects with their peers or with a teacher.
>
> Keep it simple. An inquiry project shouldn't be a big hassle to the student. Otherwise they'll learn more about the trials of science rather than the rewards. My peers first pointed this out so it seems that peer discussion and teacher discussion are essential to inquiry for students to succeed. Talking to others can help the researcher see flaws or hardships ahead of time.
>
> I keep going back to the idea of peer review, consultations with the teacher, and scaffolding. I think support from peers and from a teacher would not only thwart apparatus problems and the like, but it would also keep their spirits up in the face of difficulty. My inquiry project has definitely had its ups and downs. Since we didn't discuss our inquiry projects for decent chunk of time in class, and since I don't have a partner, I didn't have much support...Budding scientists may need more support.

In addition to working with peers, Joanne included strategies for narrowing down options for students.

> If I choose to do inquiry, I think I want to work closely with them to guide them as far as set up, materials, methods, etc. This is especially crucial with younger students.
>
> Here's my scheme: Center the inquiry around a specific topic that students could ask a lot of testable questions about. I could lead them to ask testable questions based on activities similar to the ones we came up with in our outline for today's class. As I keep mentioning, teacher review and peer review should be implemented to be sure the questions and proposals for projects really are testable. Discussion all along the ride of inquiry is essential.

In her reflections, she recognized as other participants did, how complex her inquiry project was becoming. She considered ways to help students through the process as did Amanda, but in her future classroom she envisioned her scaffolding primarily to be students helping and being helped by peers.

Part II

Using Inquiry During Student Teaching

This section attempts to answer the question: What conceptions and investigative experiences are linked with pre-service teachers' use of inquiry in the classroom? In two studies using the same investigative approach, Windschitl (2001; in press) found that of all participants, those with previous significant long-term research experiences were the most likely to use various forms of inquiry in their classrooms. By contrast, those with little or no research experiences tended to employ demonstration, confirmatory laboratory activities, and direct instruction as their main modes

Research experience	Name	Previous research/inquiry experience	Undergrad credits in sciences	Most frequent modes of instruction during subsequent 9-week teaching assignments	Use of inquiry
Significant Research Experience	David	Received NSF fellowship in pharmacology. As Ph.D. student did several studies himself that were eventually published.	60 graduate credits in Ph.D. program	Taught 10th grade biology. Used discovery activities regularly. **Used guided inquiry**, asking students "Does saliva break down starches into sugars?"	Greater Use of Inquiry
	Gina	Two research studies as undergrad in Indonesia on primate behavior. Developed questions, designed and carried out studies.	145	Taught AP biology. Required curriculum left little room for inquiry. Did use several discovery activities and confirmation labs.	
	Assan	As undergrad did study of color vision and motion detection in invertebrates. Developed questions, designed and carried out studies. Also an assistant in immunology lab as an undergraduate.	165	Taught 9th grade biology. **Used open and guided inquiry extensively.** Example: Had students use models of humans skulls to hypothesize evolutionary patterns.	
	Bill	3-quarter undergraduate research project on underwater landslides. Developed questions, designed and carried out one study.	127	Taught 8th grade earth science. Used confirmation labs regularly. Used open-ended activity once—requiring students to build a machine showing transfer of energy.	
	Amanda	As undergrad did quarter-long study of frog behavior at local zoo. Developed questions, designed and carried out studies.	115	Taught 10th grade biology. **Used guided inquiry extensively.** Example: When studying cohesion forces started with structured inquiry then allowed students to change a variable of their choosing and complete the study themselves.	
Some	Joanne	Interned in a microbiology lab. Did problem-solving to complete an assay of bacterial DNA. Did open-ended inquiry on soil samples for an undergraduate chemistry class.	108	Taught 7th grade life science and 8th grade physical science. **Used guided inquiry extensively.** Example: What causes bouncy-ness of different kinds of balls? Conducted unit on science inquiry. Did various activities on hypothesis-forming.	<<<< >>>>
	Pamela	Limited involvement in psychology research program. No other research/inquiry experiences.	83	Taught 10th grade biology. **Used guided inquiry once** in osmosis experiment.	
	Marcus	Worked as an assistant in immunology lab. Did not conduct research independently. Developed "techniques" usable in industrial settings.	110	Taught 9th grade physical science. **Used guided inquiry once.**	
	Shellie	Did undergrad. biology research with four other students examining coastal pollution. Did not collect data first hand.	131	Taught 10th grade biology and 9th grade general science. **Used structured inquiry twice.** Used some discovery activities. Students in general science class asked to assemble toy that demonstrated physics principles.	Little or No Use of Inquiry
Little or No Experience	Bria	Brief experience at archeological dig. No other research experiences.	109	Taught 9th grade physical science. Did several discovery activities. Example: How density of water changes due to temperature changes. **No forms of inquiry used.**	
	Jenelle	Limited work with chemistry professor in molecular modeling on computer.	100	Taught 11th grade chemistry. **Confirmation labs** intended to lead to an understanding of chemical formulae.	
	Nick	Was a lab technician in pediatrics department	84	Taught 10th grade biology. Used lecture and worksheets almost exclusively. **No inquiry used in any form.**	

Figure 2. Previous research experiences, credits in undergraduate science, and use of inquiry during student teaching.

of instruction. Because of the limited number of participants in previous studies in this series, data from this third cohort will be used to confirm these trends (the three studies have a total of 30 participants).

Data from the current study has indeed demonstrated that research experiences is linked with the use of inquiry activities in the classrooms. Figure 2 shows, for example, that David, who had done several research studies of his own, used guided inquiry in asking his students to design and complete an investigation on the question "Does saliva break down starches into sugars?" Likewise, Amanda, who as an undergraduate had done a quarter-long study of frog behavior at a local zoo used guided inquiry in her classroom. In fact, she scaffolded inquiry skills by guiding her students through a whole class inquiry of cohesion forces, then had them select a variable to change and conduct the resulting study on their own. Similar positive links between previous research experiences and use of classroom inquiry were found for Assan. By contrast, those that had little or no research experience (Nick, Jenelle, Bria) used occasional discovery activities or confirmation labs, but did not use any forms of inquiry.

One notable "outlier" in this data was Joanne, who had limited research experience, but who used guided inquiry extensively in her classroom. She, for example, had students design investigations of what caused "bouncyness" in balls. She also conducted a whole unit on inquiry and did various activities in hypothesis-formation. An informal follow-up interview was conducted with Joanne to better understand this connection between research experiences and her classroom use of inquiry. During this interview, she related that her "mentor" at an immunology laboratory had asked her to solve a series of problems in completing as assay of bacterial DNA. This type of experience as a "technical assistant" of scientists has not been as closely linked with participants' use of inquiry in the classroom. However, Joanne went on to say that "this whole thing [her laboratory experience] showed me how science was a process and not just a collection of facts." She made connections between the passion for science she developed, her own lack of opportunity to do inquiry in her K-12 career, and her desire to help her own students experience inquiry:

> Personally, real experimentation through research taught me a lot about this aspect of the scientific process. I guess I learned (or was supposed to learn) about scientific thinking in constructed recipe-type lab experiments in high school and college, but it was not until I did the actual tinkering myself, that I found myself really thinking about science. Really wondering. Since I didn't have the opportunity to experiment (answer my own questions) in my secondary science experience, I want to give my students the opportunity.

For Joanne, this peripheral participation in research (the kind which has not helped other participants come to see science as a process, nor had been linked with eventual uses of classroom inquiry) had transformed her thinking about science and what it could mean to young learners. This suggests that a key factor in research/inquiry experiences for pre-service teachers is not that which only immerses them as legitimate participants in authentic investigative experiences, but that also serves to help them conceptualize science as a way of knowing the world rather than as a canon of content.

Discussion/Conclusions

Data analysis is ongoing in this project, however, the following tentative summations are offered. Inquiry, as previously described, has a multitude of meanings, depending upon, among other things, the situation in which it is used and its construal with regard to available cultural models. In the case of our own methods class, "science inquiry" was taken to be more than "posing and finding the answer to a question"; there were more implicit rules that seem to define inquiry and to have guided the conduct and reflections of participants in the study. Some of these rules were *congruent with a limited view of science inquiry*:

- there is a scientific method, although it is not linear
- inquiry must be a comparison between two groups
- inquiries are synonymous with experiments

Furthermore, some of the most consistently implied rules across participants were *misrepresentations of some of the most fundamental aspects of scientific inquiry*:

- a hypothesis functions as a guess about an outcome, but is not necessarily part of a larger explanatory framework
- background knowledge may be used to give you ideas about what to study, but this knowledge is not in the form of a theory, explanation, or other model
- theory is something you might use at the end of the study to help explain results

Another theme that emerged in the journals was a relationship between participants' ongoing reports of struggles with developing suitable questions, designing investigations, and analyzing and making sense of the data, and, the emergence of a classroom model of inquiry that emphasized the need to "help" their own students engage in this enterprise. Participants identified these general strategies for instructional support (most participants mentioned at least two of these three general strategies):

1) direct instruction on aspects of inquiry (but interestingly, not on background content or the use of guiding theory),

2) adding more structure to the inquiry process (giving students a highly restricted numbers of topical options to choose from in designing their inquiry, fashioning research questions for them, requiring student proposals and approval by the teacher), and,

3) using scaffolding techniques centered on sense-making activities by students and the use of peer dialogue as a way to learn.

Given that participants saw their own inquiry projects as difficult (especially in the initial stages of developing a question and designing a study, the two aspects of inquiry which teachers rarely allow student to engage in), it may have reinforced the desire for a highly-structured version of the scientific method for use in the classroom. Using a highly-structured, highly-simplified sequence of events for their classrooms seemed appealing to several participants, who at the same time acknowledged the complexity of authentic investigations. For the beginning teacher, it may seem daunting to face 30 students, each pursuing different inquiry projects, unique approaches to collecting data, and novel ways of connecting their hypotheses, data, and conclusions.

The notions of a "scientific method" and an atheoretical approach to inquiry was reinforced not only by their own inquiry experiences, but also by what they saw in schools. Library resources (and at least one cooperating teacher) referred to confirmatory laboratory exercises as "the scientific method." Actual experiments done by students, which were not based on any explanatory model but rather were comparison between arbitrarily designed groups of plants, also served to reinforce a "science fair" notion of inquiry for one of the participants. Given the widespread (and misplaced) faith in "The Scientific Method" and its pervasive presence in texts, in teacher talk, and in classroom instructional design, it may be reasonably assumed that participants in this study had their thinking influenced by this caricature of authentic scientific investigation. Figure 3 presents a set of theoretical relationships between cultural models of "inquiry", the inquiry experiences of participants, their self-projected use of inquiry in the classroom, and their actual teaching practices.

Finally, all participants expressed enthusiasm toward their investigations. However, this excitement and the experiences with the inquiry project were not enough to compel all of these preservice teachers to use inquiry in their classrooms during student teaching. Only six of the 12 participants used some form of guided inquiry in their classrooms. As was true in the first two studies in this series, the participants with significant, long-term research experiences and science content background were more likely to use inquiry in their own classrooms. These individuals had research experiences either as undergraduates or as professionals, and in these research experiences they were all involved in developing questions, designing ways to collect data, and working toward a larger research objective.

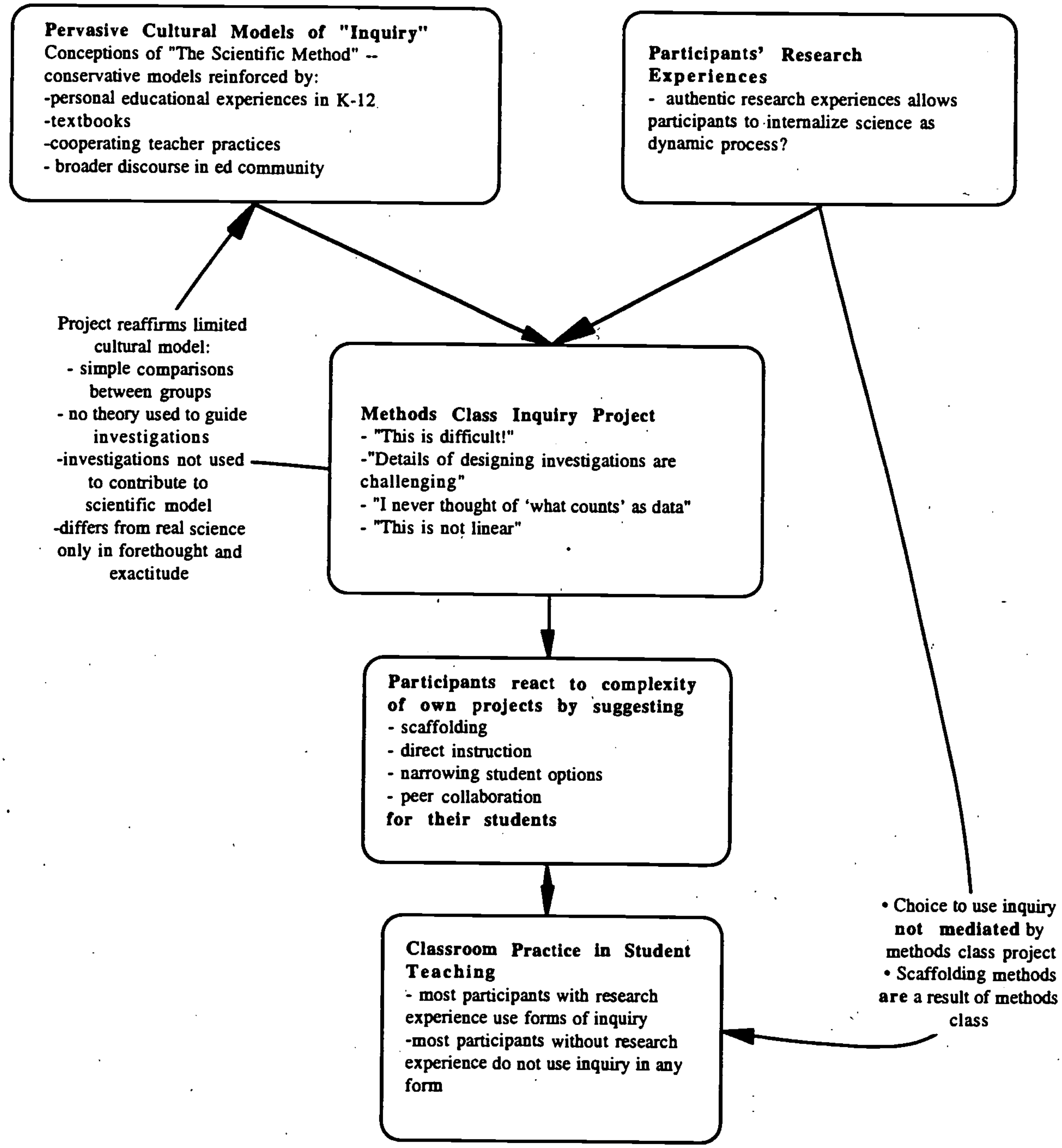

Figure 3. Theoretical relationships between cultural models of "inquiry", the inquiry experiences of participants, projected use of inquiry in the classroom, and actual practice.

Joanne, who had limited involvement on a research team and yet used inquiry in her own classroom, claimed that this limited experience with research did help her "see science as a process." This suggests that what research projects may do for prospective teachers is help them re-frame their cultural models of science from a collection of static truths to a dynamic sense-making endeavor. Involvement in research that emphasizes the technical aspects of investigations may not be enough to transform the persistent, conservative models of "the work of science."

Admittedly, there were limitations both to this study and to the methods class project. The participants were observed in a student teaching situation, not in their own classrooms as first year teachers. It is reasonable to assume that their cooperating teachers had curricula that they preferred their student teachers work with, and that they had some influence on how the participants taught. There is data to support this. Another limitation is that the methods class experience did not include explicit challenges to any participants' views of inquiry or to the conduct of their investigations. Making student teachers' beliefs and conceptions clear to themselves as well as to others may be a necessary first step in re-framing unsophisticated perceptions of science inquiry. Knowing, then, how potentially powerful inquiry experiences can be, it suggests that teacher education programs should promote some *authentic* science research experiences either in conjunction with methods classes or within other areas of the preservice program. Other studies are necessary to determine whether and how such programmatic efforts will affect teacher practice.

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Appendix A. Field Supervisor Observation Instrument

1) Kind of instruction the TEP student employed—

____a) Inquiry: *Inquiry is a multifaceted activity that involves making observations; posing questions; examining books and other sources of information to see what is already known; planning investigations; reviewing what is already known in light of experimental evidence; using tools to gather, analyze, and interpret data; proposing answers, explanations and predictions; and communicating the results. Inquiry requires identification of assumptions, use of critical and logical thinking, and consideration of alternative explanations.*

____b) Discovery activity (brief activity to exemplify a scientific principle)

____c) Confirmation lab

____d) Laboratory skill exercise

____e) Discussion

____f) Lecture/direct instruction

____g) Worksheet/ seatwork

____h) Other

If some form of inquiry used, circle ***one variation in each of the 5 rows*** that best describes the student teacher's ›roach for each of the five "essential features"? Not all 5 of the "essential features" will be observable in a given class session, :n if they are using inquiry.

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

Appendix B. Thinking about the Nature of Science (NOS)

This is an exercise to help you surface your understandings and beliefs about the nature of science (NOS). Below are 5 topics that all relate to science as a discipline. Each topic is followed by hypothetical responses from two individuals. Please indicate which of the two seem to be most related to your own ideas about the nature of science. It is possible to agree in different ways with both statements, or agree with a statement only under certain conditions. Write at least three or four lines about why you agree with one position over another, or about how you could envision both being accurate. Give examples if they help express your response. There are *no right answers*!

1) Science ideas— are they subject to change?

Allen: Changes in scientific knowledge are bound to happen because new observations can challenge our current theories. No matter how well one theory explains a set of observations, it's possible that another theory may fit just as well or better, or may explain a wider range of observations. It's like when scientists come up with new ways to describe what matter is made up of at the smallest, atomic levels or how the universe behaves—better theories always come along to replace the old.

Jorge: Science knowledge does not change over time. Once good theories and explanations are created, they apply for all time. Otherwise, why would we bother to develop them? If there are competing theories, it's a matter of who is right and who is wrong.

2) What kinds of questions can science answer?

Lativa: If scientists could examine everything closely enough, in enough detail, then eventually everything could come to be known. This includes questions about god, about what is beautiful, moral, or valuable in life. Even decisions that communities or governments make can be arrived at using purely scientific methods.

Susan: There are lots of things that can't be usefully examined in a scientific way. Beliefs that you hold can't be proven or disproved such as the existence of supernatural beings or powers, or the true meaning of life. Scientists don't have the means to settle questions of good and evil; they can only contribute to the discussion by describing the consequences of particular actions.

3) Scientific facts, laws and principles— do we discover them or construct them?

Carrie: Out there in the world, apart from humans, there are facts, laws and principles that determine how nature works. Newton's laws and the fact that helium has two protons have existed long before humans discovered them. The role of scientists is to reveal what already exists.

Maria: All scientific facts, laws, and principles are human inventions. They don't exist "out there" independent of people, but have to be constructed. The world has always behaved in consistent ways but our explanations have been a product of human thinking and argument.

4) Science: logic or imagination?

Bill: The use of logic cannot advance science. Scientific concepts do not emerge automatically from data or any amount of analysis alone. Inventing hypotheses or theories to imagine how the world works and then figuring out how they can be put to the test of reality is as creative as writing poetry, composing music, or designing skyscrapers. Even evidence that is ignored by one scientist may lead to new discoveries by another scientist who sees more imaginative ways to analyze the data.

James: Scientific arguments must conform to the principles of logical reasoning—that means you have to test the validity of arguments by applying certain criteria of inference, and common sense. Scientists may often disagree about the value about a particular piece of evidence and therefore disagree about what conclusions are justified. Using creativity and imagination distracts scientists from looking at evidence with a critical eye.

5) Scientific method

Dawnelle: Science is done by comparing control groups and experimental groups that you manipulate. Scientists always start with observations, then create a hypothesis, then figure out how to collect data, then analyze it to make a conclusion. Other ways of exploring the way the world works can be exciting and can contribute interesting information, but it is not really science inquiry.

Aaron: There isn't really one scientific method. Different kinds of scientists each have their own way of approaching inquiry. There is no fixed set of steps that all scientists must follow, no one path that leads them every time to scientific knowledge. Also, some scientists create hypotheses while they are collecting data and others change the problem they are trying to solve as they analyze their data. Some scientists like astronomers don't have experimental groups that they manipulate, but they do inquiry by collecting data through observations.

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