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ABSTRACT

Most of America's pre-service science teachers enter their preparation programs without having conducted a single inquiry in which they have developed the question being investigated or the means to resolve it. This article describes a study in which twelve pre-service secondary science teachers developed their own investigations--from formulating questions to defending results in front of peers. Data strongly suggest that epistemological beliefs, expressed within the context of the inquiry experience, had a significant impact on the conduct and interpretation of these inquiries, and that these beliefs were associated with very different plans by the participants for using inquiry in their own classrooms. One group of participants believed that inquiry was a relatively simple, linear process. These individuals mentioned few problems conducting their inquiry. In preparing to defend their inquiries, these individuals were primarily concerned with communicating the details of their study to their peers. With regard to plans for using inquiry in their own classrooms, they mentioned overt guidance and direct instruction as ways to help students complete an inquiry, but did not mention helping students make sense of the process. Another group of participants understood inquiry as a more complex set of interrelated considerations. This group claimed that they encountered more and different kinds of problems than the first group; they described preparation for their class presentation as a time to reinterpret their work and to re-represent it in a way that would make sense to others. In describing how they would implement inquiry in their own classrooms, members of this group suggested that they would include opportunities for student-student and student-teacher dialogue as well as whole-class activities aimed at helping students make sense of the inquiry process. (Contains 44 references.) (Author/YDS)

Pre-service Science Teachers and the Independent Inquiry Experience

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Abstract : Most of our nation's pre-service science teachers enter their preparation programs without having conducted a single inquiry in which they have developed the question being investigated or the means to resolve it. This article describes a study in which twelve pre-service secondary science teachers developed their own investigations-- from formulating questions to defending results in front of peers. Data strongly suggest that epistemological beliefs, expressed within the context of the inquiry experience, had a significant impact on the conduct and interpretation of these inquiries, and, that these beliefs were associated with very different plans by the participants for using inquiry in their own classrooms. One group of participants believed that inquiry was a relatively simple, linear process. These individuals mentioned few problems conducting their inquiry; in preparing to defend their inquiries, these individuals were primarily concerned with communicating the details of their study to their peers; with regard to plans for using inquiry in their own classrooms, they mentioned overt guidance and direct instruction as ways to help students complete an inquiry, but did not mention helping students make sense of the process. Another group of participants understood inquiry as a more complex set of interrelated considerations. This group claimed that they encountered more and different kinds of problems than the first group; they described preparation for their class presentation as a time to reinterpret their work and to re-present it in a way that would make sense to others. In describing how they would implement inquiry in their own classrooms, members of this group suggested that they would include opportunities for student-student and student-teacher dialogue as well as whole-class activities aimed at helping students make sense of the inquiry process.

Introduction

Inquiry is the quintessential experience of science, yet the vast majority of our nation's pre-service science teachers enter their preparation programs without having conducted a single inquiry in which they have developed the question being investigated or the means to resolve it (Cummins, 1993; Shapiro, 1996). It is unreasonable to assume that, as teachers, these individuals will spontaneously embrace the idea of using independent inquiry with their own students or feel capable of managing such complex instruction.

Despite this lamentable cycle of inexperience with independent inquiry, there are some promising intervention strategies to help future teachers. Science methods instructors, for example, can provide opportunities for pre-service teachers to conduct their own independent inquiries, and to connect their experiences with plans to use inquiry in their own classrooms. Methods classes can feature independent inquiry as an important aspect of the pre-service curriculum-- not just to talk about-- but to experience first-hand. The impact of such an experience, however, may depend on several factors, including not only the type of inquiry selected by individuals, but also the ways in which individuals interpret their experiences and the links they are able to make between their inquiry experiences and future pedagogical approaches to using inquiry in their classrooms.

In this article, I describe a study in which twelve pre-service secondary science teachers developed their own investigations-- from formulating questions to defending results in front of peers. Throughout the inquiry process, these pre-service teachers maintained a "dual journal", one part of which chronicled their plans, puzzlements, joys, and frustrations about the inquiry process, and the other part of which was a reflection about how their inquiry experience compelled them to think about inquiry instruction with their future students.

Data from these dual journals, together with interviews and additional documents, strongly suggest that participants interpreted their inquiry experiences in vastly different ways from one another and that core epistemological beliefs about the nature of inquiry have a significant impact on these interpretations as well as on the plans of participants to use inquiry in their own classrooms.

Before describing the study, however, the term "inquiry", as used in this article, requires clarification. The term "inquiry" has been applied to a wide range of intellectual activities; among these are hypothesis testing, practical problem-solving, designing models, and engaging in Socratic dialogue. Although inquiry has broad connotations and can arguably involve any of these activities, this article uses the term "independent inquiry" to represent the process of posing a question, transforming the question into a testable hypothesis, designing the means to test that hypothesis, testing it, and drawing conclusions. This sequence of events is commonly portrayed by textbooks as a linear process and is often 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 science practice, multiple steps, or phases, are considered in relation to one another at the outset of the inquiry enterprise. Hypothesis generation, data collection, and data analysis are all mutually interdependent considerations. Second, with regard to "The Scientific Method", analyses of scientific practice have shown that there is no universal method, and that inquiry takes many forms (Alters, 1997; McGinn & Roth, 1999). Some scientists formulate and then test hypotheses; other scientists, however, construct their hypotheses after experimentation, and still other scientists conduct descriptive research in which hypotheses are never formally tested.

It is not the purpose of this study to explore the various conceptions of inquiry, but rather, to better understand how pre-service teachers make sense of the process of creating and testing hypotheses. Despite the diversity of connotations for "inquiry", hypothesis testing is a valid representative of the inquiry process. It is a disciplined, canonical process that characterizes much of how science knowledge is discovered and validated. For science learners at any level, hypothesis testing is an authentic activity by which they can generate their own knowledge and develop an understanding of one of the fundamental processes by which scientists make claims about knowing the world.

I continue now with an overview of why independent inquiry is important in science education and why it has failed to become standard practice in classrooms. I then describe the current study and share findings that have significant implications for the education of science teachers.

Background

Inquiry Instruction in K-12 Classrooms

The science education community has made "authentic science" activities for K-12 students a priority of the American educational agenda (see AAAS, 1993; NRC, 1994; NSTA, 1995), and asserted that "[i]inquiry into authentic questions generated from students' experiences is a central strategy of teaching science" (National Committee on Science Education Standards and Assessment, 1996, p. 21). For a science student, developing one's own question and the means to resolve that question suggests an inquiry experience that is profoundly different from the far more common task of answering questions put to you by the curriculum using methods also prescribed by the curriculum or by the classroom teacher.

Science education researchers have developed inquiry "continua" to describe how authentic a classroom inquiry experience is, indexed by the degree of independence the student has in asking and answering questions. The lowest levels of such continua are generally referred to as confirmation experiences, in which students verify known scientific principles by following a given procedure. The next level is referred to as structured inquiry in which the teacher presents a problem for which the students do not know the results, however, students are given a procedure to follow in order to arrive at the correct answer. In guided inquiry, teachers provide students with a problem to investigate but the methods for resolving the problem are left to the student. In open or independent inquiry, teachers allow students to develop their own questions and the methods to resolve those questions (see Germann, Haskins, & Auls, 1996; Herron, 1971; Schwab, 1962; Tafoya, Sunal, & Knecht, 1980 for various ways of classifying classroom inquiry).

The deceptively minor differences between structured, guided, and independent inquiry have, in fact, monumental implications for students' practice. For example, guided inquiry is a far more complex process than structured inquiry. As opposed to having hypothesis testing procedures laid out for them (as in structured inquiry), students who engage in guided inquiry must take the teacher's question, transform the question into a testable hypothesis, design their own ways to collect data (a process that often involves background knowledge, creativity, and persistence) and coordinate data collection with analysis. Because learners must create data that they believe will answer the inquiry question, guided inquiry can be a watershed experience during which learners understand how evidence and argument are marshaled to support knowledge claims.

In independent inquiry experiences, the teacher may circumscribe a subject matter area for investigation, but otherwise the learner has a universe of possibilities from which to fashion a question. Crafting a question that is meaningful, consistent with existing theory, and testable is an ill-structured problem in itself. For this reason, independent inquiry is an even more challenging endeavor than guided inquiry for learners to participate in and for teachers to facilitate in classrooms.

Unfortunately, inquiry in any form has not yet become a characteristic of science classroom practice (Wells, 1995). In classrooms where it does take place, confirmatory or structured inquiries are far more common than guided or independent inquiries. There are many reasons for this: most science teachers view inquiry as difficult to manage, many teachers believe inquiry instruction is possible only with above average students, and science teachers are generally confused about the meaning of inquiry (Welch, Klopfer, Aikenhead, & Robinson, 1981). Also, many activities start out as inquiry but tend to degenerate into pseudo-inquiry because of class management difficulties (Hodson, 1988).

Part of the problem in understanding what inquiry should be is associated with textbooks-- they function as the defacto curriculum in many classrooms and contain primarily cookbook exercises labeled as inquiry. A study of several popular texts for junior high school science revealed a total absence of independent inquiry activities (Pizzini, Shepardson, & Abell, 1991). Furthermore, the confirmatory exercises described in these texts are more welcome by those teachers who feel pressure to "cover" an ambitiously broad and desperately thin curriculum. This agenda encourages a culture of rote learning and precludes spending time on more authentic forms of inquiry. In such institutional environments, teaching and learning that is not pre-scripted and geared toward "right answers" is viewed with suspicion (Gabella, 1993).

To summarize, independent inquiry is a double-edged sword: it is a complex, authentic activity that provides insights into the canonical practices of science, however, in using independent inquiry in the classroom, teachers face a number of significant challenges including understanding what inquiry is, inserting inquiry opportunities into content-oriented curricula, and managing students' inquiry activities.

The Inquiry Experiences of Pre-service Teachers

Science teachers require experience with independent inquiry to integrate it successfully into the classroom culture; acquiring this experience should obviously begin before they become teachers. Let us turn our attention to the pre-service experiences of science teachers, beginning with undergraduate science courses and ending with instruction in science methods classes.

Of all the professions, educators have the longest apprenticeship of learning by being students and by observing teachers for many years (Eddy, 1969; Lortie, 1975). Most teachers are products of traditional schooling; as learners, they are exposed to teacher-centered instruction, fact-based subject matter, and drill and practice (Russell, 1993). These experiences furnish them with mental models of teaching, and, these models of how they were taught shape their behavior in powerful ways (Ball, 1988). Teachers use these models to imagine lessons in their own classrooms, develop innovations, and anticipate learning outcomes (Kennison, 1990); they are less likely to be guided by instructional theories than by familiar images of what is "proper and possible" in classroom settings (Zeichner & Tabachnick, 1981; Russell, 1993).

Much of what prospective teachers learn about teaching also comes from their experiences as undergraduates (Grossman, 1988). As with pre-college schooling, instructors in higher education not only teach the content of their courses, but they also model the 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, interviewed several lab assistants in an undergraduate biology course and found that much of what went on in the classroom was highly scripted and tightly controlled. One of the assistants explained:

> The students get confused when [the lab book] talks about hypothesis testing, because the labs we do obviously must work, otherwise then they would just get confusing results and make no headway. But since they have to work, you have to do something that has been done before...That hypothesis is not really a hypothesis, its um, its pretending its a hypothesis (p. 304).

Another assistant suggested that the difficulty in inquiry was not testing the hypothesis, but in identifying fruitful questions. He was unsure how this could be taught, commenting: "I don't know how to teach it. I think I need to be taught it" (p. 304). Another graduate assistant said that, because the students had not generated their own problems or created their own hypotheses, they lacked the focus necessary to carry out the inquiry. Among other consequences of this, the students experienced difficulty understanding the reason for their own data collecting.

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. Academic disciplines do not simply consist of concepts and organizing frameworks; disciplinary knowledge includes understanding the ways new knowledge is brought into the field. Schwab (1978) defined this as 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. These are the principles by which new knowledge is introduced and validated by that community.

Researchers have noted wide variation in the knowledge that beginning teachers have of the syntactical structures of their disciplines. The syntactic structures of a discipline are usually presented in advanced, graduate-level college courses, as students move beyond learning the content of the discipline and begin to conduct their own inquiries. If pre-service science teachers have had these kinds of experiences, they are more likely to know about the syntactic structure of science, and, as teachers, they tend to include this aspect of the subject matter in the curriculum.

For teachers familiar with the syntactic structures of science, biology class is not just about memorizing phyla, it includes discussions and activities aimed at developing an understanding of the methods of science (Grossman, Wilson, & Shulman, 1989). However, teachers who lack knowledge of the syntactic structure of their discipline are less able to incorporate that aspect of science into their curriculum. A lack of syntactic knowledge may also limit prospective teachers' abilities to learn new information in their fields. They may be unable to determine the validity of claims within a field and find themselves unable to articulate the grounds to counter a specious argument, even if they are aware of its dubious nature.

Science teachers appear to enter their professions with serious experiential shortcomings. How can the science education community reconcile the impoverished inquiry histories of pre-service teachers with the expectations that, as products of the K-16 educational system, these individuals will move into our classrooms and offer independent inquiry opportunities, anticipate the pedagogical challenges inherent in such activities, and scaffold the efforts of young learners as they develop the skills necessary for inquiry? There have been calls to integrate inquiry experiences into not only undergraduate science courses but into teacher education courses as well (Tamir, 1983; Welch, et al., 1981). Many teacher education programs have begun to promote knowledge of the discipline as well as content knowledge for their pre-service teachers. It is reasonable to assume that some methods instructors are incorporating inquiry experiences into their courses, however, few accounts of these experiences have been published and little is understood about the impact of such experiences on pre-service teachers.

In one study of 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 appreciated the need to make changes in the design of the investigation in order to solve the problem and stressed the importance of perseverance as well as skills in communicating results with others. Perhaps the most interesting finding was that those students with strong backgrounds in science made fewer changes in their thinking about the nature of science and scientific thinking. This is one of the few studies that has described independent inquiry experiences for pre-service teachers. Clearly, the research community needs to better understand how pre-service teachers interpret inquiry experiences and assess the impact it has on their ability to implement inquiry practices in their own classrooms.

Purpose

The purpose of the current study was to investigate how pre-service science teachers make sense of their own independent inquiry experiences and how they use these experiences to plan for inquiry in their own classrooms. The specific questions addressed in this study were: 1) how do participants' general perceptions of inquiry influence the way they conduct and interpret their own inquiry? 2) do patterns emerge across participants in the way they interpret their inquiry experiences? and, 3) how are participants' interpretations of their inquiry experiences linked to plans for using inquiry with their future students?

Context

Participants

The twelve participants in this study were members of a secondary science methods class at a public university in the Northwest. The teacher education program at this institution is relatively small, and is dedicated to producing graduates who will assume leadership roles as 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. The program grants a Masters in Teaching degree and all candidates must enter with bachelor's degrees in some area of science. Many also have prior work experience in science or technology areas. The twelve science students in the current study were part of a larger secondary cohort of about fifty education students who took most courses together and attend methods classes in their subject-specific groups.

The methods class was a two-quarter course and was taught by the author. Course topics included the nature of science, goals and objectives in science teaching, lesson planning, unit planning, laboratory work, inquiry, problem-based instruction, conceptual change teaching, constructivist approaches to science teaching, technology in science teaching, curriculum, and safety.

The Inquiry Project

The first two weeks of the course were designed to develop a foundational understanding of science as a way of knowing the world and finding out what scientists actually do. During the third class session of the fall quarter, the instructor initiated a discussion about inquiry in the science classroom and the role of scientific approaches in generating new knowledge. This topic laid the groundwork for later discussions about what it means to be science-literate and how one could use this knowledge as a way to develop goals and objectives for instruction.

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, etc. Students, however, were unable to articulate what the alternative process might look like, having almost no relevant experiences to draw on.

For the past three years, I have asked my methods students how many of them have, in any science class, generated their own question for investigation and means to resolve the question. Remarkably, not one student has stated that they have conducted independent inquiry-- at any level of science education. Because these pre-service teachers have had no experiences with independent inquiry, and because they have a poorly-articulated understanding of hypothesis testing, they are unlikely to be able to plan lessons involving independent inquiry for their own students, to anticipate the challenges that their own students might face in developing questions and methods, and, in general, they would be inadequate mentors to their students.

In response to this bleak situation, I asked my methods students to engage in an independent inquiry as part of the class. Students were encouraged to spend a week simply observing their local environment and considering questions of interest that came to mind. The questions could be about animal behavior, weather phenomena, technology or any other topic of interest. Students were then asked to resolve their question through hypothesis testing and defend their results to the class in a formal presentation.

Tools for Reflection

Prior to the inquiry, most of the students acknowledge that hypothesis testing is not a linear process. To make the non-linearity of this process explicit, I supplied them with a blank line graph that had the conventional steps of the scientific method on the vertical axis in the order that they are thought to occur (i.e. observing, generating a question, transforming the question into a hypothesis, developing a method to collect data, collecting data, analyzing data, drawing conclusions). The horizontal axis is marked in arbitrary units of time. Over the course of their investigation, students graph their movement from one phase of hypothesis testing to the next (Figure 1).

The main tool for students' reflection, however, is a journal in which they record the details of their inquiry "journey." The journals typically include a range of written reflections, including not only the straightforward reporting of hypothesis testing procedures, but also the frustrations, triumphs, second thoughts, and false starts associated with independent inquiry. In addition to recording these thoughts, there was also a parallel record kept by students. Each time they entered thoughts about their inquiry project, they also described how these experiences were influencing their thinking about organizing inquiry 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 how those experiences could translate into a framework for working with future students.

The journals, then, were more than records of events-- they were tools for aiding reflection. Definitions of reflective thinking range from a focus on specific aspects of teaching, learning, and subject matter (Cruickshank, 1985) to the macro aspects of the sociopolitical and moral principles of teaching (Liston & Zeichner, 1987; Tom, 1985). The working definitions for this study fell toward the former end of this continuum. 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 (Johnston, 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, which in this case is completing the independent inquiry. The students' journals, together with a set of questions supplied by the instructor to prompt reflection (found in Appendix A), 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 make this dialogue explicit to the student.

The students' inquiry activities encompassed a wide range of interests. There were investigations of such topics as bird-feeding behaviors, sunsets, diapers, electrical conductivity of fruits, and the insulation qualities of fabrics. Students were given five weeks to complete their inquiry, at the end of which they prepared a formal presentation and a defense of their findings to the rest of the class. Thoughts about preparing for the presentation were the final entries in their journals.

Method

During the first week of the methods course, participants were asked to submit a written description of how they viewed the relationship between the phases of inquiry, and to describe, in terms of metaphor, the inquiry process. Metaphors have been used to effectively study how teachers see themselves in a particular context or how they understand processes or structures in their environment (Carter, 1990; Clandinin, 1986; Clandinin & Conelly, 1986; Marshall, 1990; Russell & Johnston, 1988).

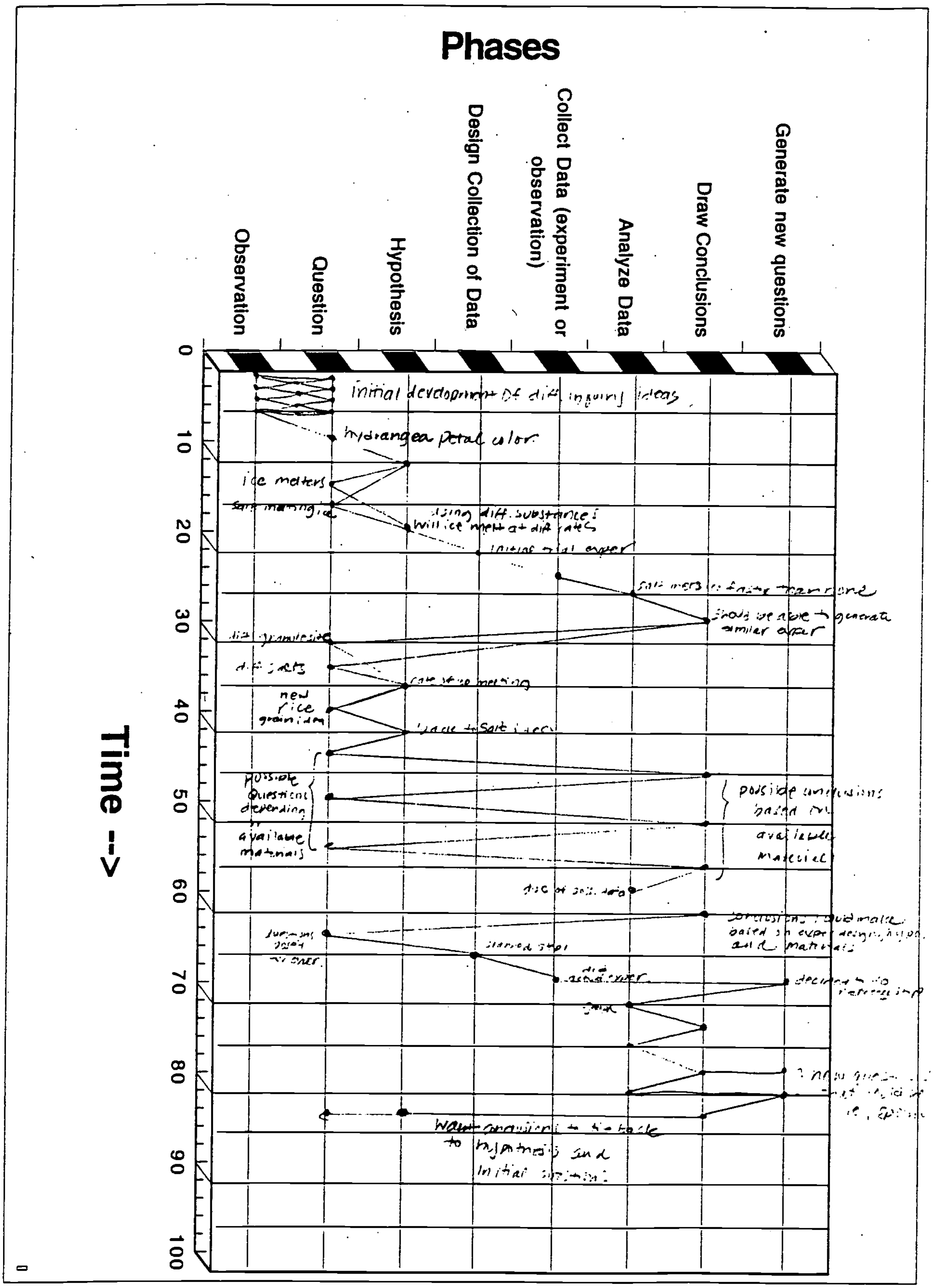

Figure 1

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During the second week of the course, participants were asked to begin thinking about an independent inquiry they could conduct that could be completed in five weeks. Participants were told that their inquiry would culminate in a final presentation to the class in which they would defend the quality of their question, their data collection procedures and analyses, and their conclusions. 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. In order to facilitate an awareness of their movement through the inquiry process, they were asked to create a concrete representation of their activities in the form of a graph that traced their movements from one phase of hypothesis testing to another.

After the final presentations, students were interviewed about their personal history with inquiry in science classes at all levels, how they made sense of their own inquiry project, and how they translated their experiences into plans for using inquiry with their future students.

Data Sources / Analysis

Primary data sources included participants' pre-inquiry written descriptions of the relationship between the phases of inquiry, their metaphors for inquiry, entries from their reflective journals, and post-inquiry interviews. Other data sources included posters and data displays used in the final presentations, as well as videotapes of the presentations.

Data collection procedures were directed primarily at revealing patterns in how individuals were making sense of their inquiry experiences, and how individuals used these interpretations to consider suitable inquiry experiences for their future students. I began by coding the pre-inquiry statements and the journals' contents, and identifying emerging patterns. Tentative hypotheses were formed about the links between the various experiences and interpretations of individual participants and also about similarities among groups of individuals who shared common interpretations of their inquiry experiences. Interview protocols were then constructed to probe for additional evidence in support of these hypotheses. The data were incorporated into cross-case analyses to better understand the interaction between particular characteristics of the preservice teachers and the independent inquiry experience (Glaser & Strauss, 1967; 1970). Multiple cases are useful to shed light on specific conditions under which certain findings occur; they invite comparisons across individuals while preserving the uniqueness of the individual observations (Noblit & Hare, 1983).

Findings

How Participants Characterized Inquiry

Analysis of pre-inquiry statements and journal entries revealed that participants had different characterizations of hypothesis testing, and that these characterizations were linked to the way they approached their own inquiry project. These characterizations were also related to the kinds of situations they perceived as problematic during their inquiry, to the perceived purpose of presenting to peers, and, most importantly, to their intentions of using inquiry in their own classrooms.

Analysis of pre-inquiry statements, journals, and interviews indicated that were three categories of participants' interpretation. Those who understood inquiry as a linear process (Group I), those who understood inquiry as a bi-directional process (Group II), and those who understood inquiry as a process involving mutually interdependent considerations (Group III). Figure 2 shows how individuals fit into each of the three groups and summarizes additional characteristics of individuals' experiences described later in this article.

Five individuals described inquiry as a linear process. They believed that hypothesis testing is a matter of stepwise movement from one phase to the next until the process is complete. The phases are discrete tasks, the requisites of which are shaped only by the details of the previous phase. These participants rarely projected how a phase might be procedurally or conceptually linked to an upcoming phase (e.g. how the way a hypothesis is stated affects the analysis of the data). One of these individuals, Jonathan, (pseudonyms used throughout) commented in his journal:

> This inquiry project was a very linear process. I had to go through each step before I got to the next. I was not, with the experiment I chose to do, allowed to try something else after I started the experiment.

Another student named Kim wrote:

> ...it was very linear, going from collecting data to analyzing data to making conclusions to generating new questions, but along the way I continuously questioned the process to make sure I was doing "good science".

Individuals in Group I rarely, if ever, suggested that problems encountered during a phase might cause the investigator to reconsider previous phases. During the data analysis phase and the conclusion phase these participants did not reflect back on whether or not they were answering their original question. Several of these

Participant & Inquiry topic	Perception of the inquiry process	Metaphors for inquiry	What participant considered problematic about inquiry*	Insights gained during preparation for defense in front of peers	Impact of inquiry on designing experiences for own students
Glen / Purity of drinking water	Linear process	Digging for gold in the right spot	Restating hypotheses after data collection, accepting results contrary to the stated hypotheses	Important to decide what data to include on your poster	Important for teacher to help students develop testable hypotheses
Kim / Efficacy of anti-bacterial products	Linear process	Building a pyramid layer by layer	Collecting accurate data	Important to communicate results clearly to peers	Teacher responsible for students' questions and methods via direct instruction
Patrick / Thermal insulation of fabrics	Linear process	Climbing stairs	No problems reported	No insights reported	Allow students to fail in order to demonstrate scientists can fail
Jonathon / Models of soil erosion	Linear process	Repairing a VCR	Logistical problems with data collection	Students should have rubric so they will know how they will be graded on performance	Give students choices in asking questions, go from simple inquiries to complex
Charles / Absorption properties of diapers	Linear process	Jumping off a cliff into the water	Inventing data collection techniques, operationalizing definitions	Hard to make solid claims based on data	Use guided or structured inquiry only
Shawna / Effectiveness of hand cleaners	Bi-directional process	Building a house on a foundation	Collecting accurate data, changing data collection methods in mid-inquiry	Reinterpret findings from audience's viewpoint, revisit assumptions	Students need time to generate questions, let students re-evaluate what they are doing in mid-study
Leslie / Pollution's effect on leaves	Bi-directional process	1) Sisyphus, 2) dancing, 3) swimming upstream	Eliminating bias, inventing data collection techniques	Make sure students have safe environment to share results	Give ample time for all phases, graphs are important to show results to peers
Deanne / Cycles of cat behavior	Bi-directional process	Phases like spokes on a wheel all connected at the hub	Subjectivity of classifying animal behaviors	Reinterpret findings from audience's viewpoint, revisit assumptions	Students write proposals before investigating, get teacher's feedback
Alicia / Feeding habits of birds	Mutually interdependent process	Adventurers finding an all-water route around the world	Determining what kind of data are related to hypothesis, data analysis influencing claims of results	Reinterpret findings from audience's viewpoint, revisit assumptions	Do whole class exercise about what a good inquiry question is, engage students in dialogue
Amanda / Factors affecting sunsets	Mutually interdependent process	Roller-coaster ride with alternate routes and loop-backs	Subjectivity in assessing sunsets, continually assessing relationship between hypothesis and data collection	Reinterpret findings from audience's viewpoint, revisit assumptions	Allow group brainstorming about hypotheses, work in groups to develop investigations
Kevin / Electrical conductivity of fruits	Mutually interdependent process	Fixing a car using different hypotheses until problem is solved	Hypothesis biases interpretation of data, necessity of multiple pilot studies to really understand original question	Reinterpret findings from audience's viewpoint, revisit assumptions	Do background research on topic, discuss inquiries in groups and get regular feedback from teacher
Craig / Thermal insulation of plastics	Mutually interdependent process	Detective entertaining multiple hypotheses while looking for evidence	Collecting data that is relevant to question, working within the confines of a yes/no hypothesis	Good way to share results with others	Allow mistakes as learning experiences, do first inquiry as whole-class activity and discuss the process

*All participants reported difficulty in developing questions

Figure 2

individuals did claim that the process of inquiry was cyclical rather than linear, but they based this interpretation on the notion that once a conclusion is reached, it generates additional questions that begin a new inquiry cycle.

Three individuals were placed into Group II-- those who understood inquiry as a bi-directional process. These participants believed that problems encountered during hypothesis testing regularly required that the inquirer return to earlier phases to make adjustments. For example, during data collection one might realize that they had asked an inappropriate question to begin with, and that the question would have to be reframed. The sense of relationship between phases, then, included the idea that problems or opportunities encountered at different points during the inquiry process would regularly compel you to return to previous phases in your study and to re-think or re-design them. Deanne, who studied cat behavior, encountered problems with data collection and connected this to a generalization about inquiry:

> How specific do I get? Do I just classify behavior as resting, bathing, eating, ect.? Or do I need to specify-- licking paw, 30 seconds...tilts head for 15 seconds. I think this may be toooo tedious, I will try behavior-lumping I think... I guess this would be an example of a non-linear pattern of scientific method, as you go through the process thoughts change, new ideas form and then you must reform the original idea and make sure you are testing for the right thing.

The four participants in Group III described <u>inquiry as a process involving mutually interdependent considerations</u>. Their remarks in both their pre-inquiry statements and their journals reflected the belief that the phases of inquiry only make sense in relation to one another and that phases have to be considered simultaneously at the outset of the inquiry. For example, Amanda, who was studying sunsets, wrote that during the initial phases of inquiry she had to consider multiple criteria simultaneously:

> [My] hypothesis was: The higher the pollution index rating for the day, the deeper red the sunset at night. So--- more and more questions came up-- What pieces of data test my hypothesis? What related directly to my question? By going back and forth between my hypothesis and data collection I was able to define how to collect data and reinforce what my hypothesis was.

Another student, Alicia, also emphasized the necessary coincidence between the inquiry questions and the methods to answer those questions:

> Still trying to define a testable hypothesis. Still feeling that pondering the data collection method drives revisions in the questions and hypothesis...in thinking about the question you necessarily begin thinking how you might investigate it-- you have to think about the feasibility of measurement and imagine whether your envisioned method will yield the results you want.

The clearest differences in the perceptions of inquiry were between the individuals who saw inquiry as a linear process (Group I) and those who saw it as a process involving mutually interdependent considerations (Group III). The three individuals who saw inquiry as a bi-directional process shared characteristics with both of the other two groups, and in many respects, were difficult to identify as a discrete group.

<u>Participants' Metaphors for Inquiry</u>

Before conducting their inquiry, students were asked to submit metaphors that they believed represented the nature of the inquiry process. The character of these metaphors were closely associated with the participants' pre-inquiry statements about inquiry and with the way in which individuals conducted their inquiry. Individuals who believed in inquiry as a simple, linear process (Group I) suggested metaphors that were equally simple. These metaphors emphasized either the sequential nature of the hypothesis testing process (e.g. building a pyramid layer by layer, building a house from the foundation up, or walking up a set of stairs), or, the metaphor emphasized the quest for a single "right answer" (e.g. digging for gold in the right spot, solving problems with your VCR). Two of the three individuals who saw inquiry as a bi-directional process (Group II) chose metaphors that were indicative of a more complex process. One student offered three metaphors: "that mythological guy who was rolling the stone up the hill, swimming upstream, and dancing...because they all involve one step forward and two steps back." Individuals who saw inquiry as a process of mutually interdependent considerations (Group III) used metaphors that suggested inquiry was even more complex, such as a multi-track roller coaster ride with alternate routes that could loop you back to a place you had been before. Another individual used the metaphor of a detective who had to consider a range of possible hypotheses at the same time he examined a crime scene for evidence.

<u>Participants' Perceptions of What Was Problematic About Their Inquiry</u>

One illuminating analytical category that emerged from the journals was situations that participants considered to be problematic during their inquiry. In their journals, participants described a range of problems.

One problem common to all participants was developing a suitable question. All twelve participants mentioned difficulty in crafting a question that was interesting to them, challenging, and testable-- most expressed frustration at the process. As a group, participants suggested strategies for helping their own students develop questions and several participants suggested that their own students be given at least two weeks to come up with a testable question. There was no identifiable relationship between difficulties in developing questions and any other participant characteristics.

Participants, however, also found other aspects of inquiry difficult and there were clear differences in what was considered problematic between participants in Group I and those in Group III. Those in Group I described fewer problems overall than those in Groups II or III. Two individuals in Group I, in fact, claimed that they encountered no problems at all, and reported in their journals little more than what one would find in a laboratory notebook. The problems that were cited by this group of participants were primarily concerns about the operationalizing of variables, the logistics of collecting data, and accuracy in recording data.

Participants in Group III also wrote about problems with designing ways to collect and analyze data, as did other participants. In addition to these concerns, however, they wrestled with questions about the relationships between inquiry phases. For example, they asked themselves how well their data answered their original questions, or whether their hypothesis was affecting the way they observed phenomena. Other students, like Craig, thought the nature of hypothesis testing itself was problematic; he said:

> Some teachers stress the need for a "yes or no" answer to a hypothesis. For example, will a bungy cord absorb more force than a steel cable? This may be helpful for students without experience in developing hypotheses or designing experiments. But it is not necessary and actually limits the possible questions to be investigated. I could ask: which rope absorbs the most force? With the more open-ended question, we are able to test more conditions, in this case, more different kinds of rope and compare them with each other.

Perceptions of the Experience of Presenting to Peers

In preparing to present findings to their peers, three of the four individuals in Group III and two in Group II expressed some surprise that it became a time to step back from immersion in their work and to re-evaluate the assumptions upon which their inquiries were founded. Kevin, for example, said in his journal:

> The presentation was beneficial because it put the experiment in a different light...I became cognizant of subtle things about my experiment that could have been done better. Little things came to mind like how confidently I was saying that oxygen was the key variable when I was only really inferring that it was. The presentation experience was a good way to heighten my awareness about what I had done and what I could have done better.

Individuals in Groups II and III further expressed that preparation for the presentation forced them to reinterpret their findings and reconceptualize their work from the eyes of another. It was not a simple "reporting of results." They wrote in various terms about the notion of intersubjectivity--- how the study would be perceived by others who were neither as familiar nor as invested as they were themselves in the topic. Amanda said:

> This part of the inquiry really made me rethink my whole project. Trying to make sure that what I did made sense to others changed my perception quite a bit. I had to make sure that I fully understood what I did, or at least acknowledged what I didn't understand. It was at this point that I even decided to re-write my hypothesis. I didn't change the meaning of it, just the words for anyone who looked at my poster. It was a great experience, something that is so clear to me is challenged, suddenly new questions came up...my classmates didn't see it as clearly as I did.

None of the participants in Group I described any sense of "stepping back" to reevaluate the coherence of their inquiry or determine whether they answered their original questions. These individuals did not include any mention of how their study would be perceived by an audience that was unfamiliar with their work. This group of participants prepared for their presentation by "sharpening up" the details of their study; they were concerned about organizing and delivering the results of the study to others without necessarily revisiting the assumptions that the studies were based on or anticipating alternative ways that audiences could interpret their work.

How Participants Planned to Use Inquiry With Their Own Students

All participants claimed that their experiences strongly influenced their thinking about conducting independent inquiry with high school students. They developed many thoughtful ideas for scaffolding learners' first engagements with inquiry. Some of these were: 1) conducting a whole-class guided inquiry before allowing individuals to do independent inquiry, 2) prompting students to start with inquiries that involved minimal numbers of variables, and, 3) having students draft inquiry proposals for teacher review before committing themselves to a project. A complete summary of their recommendations is presented in Appendix B.

With regard to facilitating student inquiry, there was one distinguishing commonality of individuals in Group III-- they emphasized the importance of helping students make sense of the inquiry process. Whereas participants in Group I discussed how their own students' might be helped to complete a successful inquiry activity, participants in Group III focused on how they could help students understand inquiry as a process. Specifically, these participants stated that they would give their own students opportunities for inquiry-oriented dialogue with each other as well as with the teacher. For example, Amanda stated:

> That's why I think it would be beneficial to have my students get in groups and talk to each other about what they're doing throughout the inquiry process. There's so much to learn from other students' views...I would really like them to have time to discuss together what they're working on and to help one another.

Other participants in Group III described class activities that would help students make sense of the different phases of inquiry. In this case, Alicia describes an activity in which students think about the nature of questions and how different types of questions are amenable to hypothesis testing:

> I can also see doing inquiry in pairs so they could discuss issues together-- also, a set of sample questions could be generated by the class, and then classified into "wonderment", basic information, or covariation questions. I think this is a useful way of classifying and examining questions with the purpose of identifying those that can be productively investigated.

As a group, these participants saw student inquiry as less of an exercise and more of a creative, interpretative experience. By contrast, those in Group I were more concerned with teacher guidance and in some cases teacher control over students' activity. Kim remarked:

> I feel it is up to the teacher to make sure the students have good questions, good methods, and a good conclusion...I think I will have the students write a proposal so I can stop the students from starting an unfeasible question which would be impossible to answer, or to stop them from collecting the wrong data for a certain question.

Charles admitted outright reluctance to allow independent inquiry in his classroom:

> I might give [students] a major question to answer, maybe even a couple of smaller questions to lead them down a path of understanding....mostly in my class the inquiry will be somewhat guided.

Other Participant Reactions to the Inquiry Projects

Despite major differences in how participants viewed inquiry and the differences in how they planned to implement inquiry in their own classrooms, there were some similarities across all participants' perceptions. All journals expressed excitement and generally positive emotions about the projects, especially when individuals were at the stage of collecting data. Participants became quite invested in their work and stated that they clearly understood the importance student interest in such long-term projects. They saw the necessity for investment in independent inquiry projects because it would sustain students' motivation through a process that is inevitably longer than most science projects, more complex, and more likely to present set-backs.

Almost all participants acknowledged that they were using advanced subject matter knowledge to solve or head off problems, and, that this kind of knowledge would be unavailable to their own students. This prompted several participants to suggest that their future students do substantial background research on their preferred topic before embarking on independent inquiries.

Discussion

The analysis of multiple criteria placed participants in one of three groups: those who understood inquiry as 1) a linear process (Group I), 2) a bi-directional process (Group II), or 3) a process of mutually interdependent considerations (Group III). Groups I and III were most clearly distinguished from one another. Participants in Group II shared some characteristics with each of the other two groups and were more difficult to categorize with regard to their understanding and beliefs about inquiry.

Those participants who believed that inquiry was linear process chose metaphors that depicted inquiry either as a stepwise movement toward a fixed point, or the investigation of a mechanical problem for which there was presumably a "correct" answer. In their journals, these individuals mentioned few or no problems conducting their inquiry; the problems they did recount related to the accuracy and completeness of their data collection. In preparing to defend their inquiries, these individuals were primarily concerned with communicating the details of their study to their peers. With regard to plans for using inquiry in their own classrooms, these individuals indicated they would facilitate their students' inquiry efforts through overt guidance and direction, and did not mention the importance of student dialogue or broader sense-making activities-- their pedagogical thrust was directed towards students completing a successful inquiry.

By contrast, those who understood inquiry as a set of interdependent considerations tended to choose metaphors that suggested inquiry was a more complex process in which multiple hypotheses had to be entertained simultaneously or in which the inquirer would inevitably have to revisit different phases to make sense of the whole process. In their journals, this group recounted far more problems with their inquiry projects, despite the fact that their inquiries were at least as sophisticated and as well-executed as the members of Group I. Some of their problems centered around the collection of data, but there were also concerns about the relationships between their questions, data collection, and conclusions. Three of the four members of Group III described preparation for the class presentation as a time to reinterpret their own work and to re-present it in a way that would make sense to others. In describing how they would implement inquiry in their own classrooms, all members of this group suggested that they would include opportunities for student-student and student-teacher dialogue, and conduct whole class activities aimed at helping students understand the relationships among the phases within the inquiry process. Their emphases were on helping students both complete inquiry and understand the process.

Was there a theoretical explanation that could account for similarities within and differences between the three groups? When one considers that inquiry is essentially a knowledge construction experience, it is reasonable to assume that the epistemological frameworks of the participants play a role in their beliefs about inquiry, in the conduct of their activities, and even in their reflections about the process. Epistemology is the study of the grounds and limits of knowing about the world. The epistemological beliefs of teachers have been associated with their teaching style, their expectations of students, and the treatment of subject matter in class. Epistemological beliefs, however, have been routinely assessed with surveys and interviews that are not referenced to any immediate experiential context (such as an inquiry project), leading some researchers to claim that "no studies to date have attempted to look at beliefs in a more situated fashion" (Hofer & Pintrich, 1997, p. 121). Others have suggested that "it might be appropriate to speak of epistemological positions only in specific contexts rather than as descriptors of an individual's view in general (Roth & Roychoudry, 1994, p. 17). The current study gives a glimpse of how individuals' epistemological beliefs are revealed within the specific context of an independent inquiry project.

Various dimensions of epistemological beliefs have been posited, including how individuals accept various sources of knowledge as valid, what constitutes justification for knowing, the degree to which one can be certain of knowledge claims, and belief in the simplicity or complexity of knowledge. Although there are some disagreements about the existence or independence of these dimensions, the latter two aspects (certainty and simplicity) seem most relevant to the analysis of the independent inquiry experiences of participants in this study.

Individuals with unsophisticated epistemological beliefs see knowledge as an accretion of discrete, unambiguous, and objective facts. Those with more sophisticated beliefs see knowledge as a complex set of interrelated concepts, subject to individuals' interpretation based on the context in which the knowledge is considered (Hofer & Pintrich, 1997). These theoretical polarities in how individuals perceive knowledge and knowing are congruent with the ways in which participants in this study viewed the inquiry process and went about gaining knowledge themselves.

The participants who understood inquiry as a linear process subscribed to an oversimplified view of knowledge and gaining knowledge. Inquiry-as-linear is a simple conception of a complex process that effectively filtered the inquiry-related experiences of individuals in Group I so they were congruent with this reductionist model. Beliefs about inquiry as a simple, unambiguous, or objective process were revealed in their metaphors, in the kinds of situations they considered problematic, and in their attitudes about presenting to their peers. Perhaps most importantly, participants' view of inquiry as a straightforward procedure was translated into a complementary way of using inquiry with their own students in which they planned to emphasize the skills necessary to complete an inquiry and did not mention pedagogical activity directed toward student understanding of the process.

The participants who understood inquiry as a process involving mutually interdependent considerations consistently demonstrated that they believed inquiry was complex, and, that acts of interpretation were essential to understanding the processes as well as the products of inquiry. These perspectives are congruent with the more sophisticated epistemological positions of knowing as a complex process and knowledge claims as highly contextualized. These participants emphasized intersubjective sense-making in the way they wrote about presenting to peers and also in the way they planned for extensive opportunities for student sense-making dialogue as part of their pedagogical approach to teaching inquiry. These individuals seemed to intuitively understand the link that Vygotsky expressed years ago between dialogue and understanding: "The more complex the action demanded by the situation and the less direct its solution, the greater the importance played by speech in the operation as a whole." (1978, p. 25-26).

It was predictable, to a degree, that participants would have varying levels of epistemological sophistication and that these levels would relate to their view of inquiry, because inquiry is a method for producing knowledge and, correspondingly, epistemology is the study of knowledge and knowing. However, the particular ways in which these beliefs would affect the interpretations of their inquiry experiences and their plans for designing inquiry experiences for their own students were not as predictable. As with epistemological studies in general, it is not clear whether underlying beliefs are causing participants to make choices about conducting inquiry, or, whether these choices are simply manifestations of the epistemological beliefs that emerge in the context of independent inquiry. Most likely, underlying epistemologies function like lenses through which one anticipates, interprets, and evaluates the world.

Epistemology appears to be an important theoretical construct with which to understand the novice teacher's beliefs about inquiry and about inquiry instruction. What is less clear, however, is how these independent inquiry experiences can be used to improve pre-service teachers' understandings of inquiry and make these individuals better mentors for their future students. Simply providing them with their own independent inquiry experiences appears to be a half-measure. It may be necessary in methods classes to explicitly address epistemological issues within the context of individuals' inquiries, and, to make clear how individuals' interpretations of inquiry may be shaped by unexamined beliefs about the certainty/tentativeness and simplicity/complexity of knowledge.

Conclusions

Independent inquiry is the hallmark experience of science. Most prospective teachers, however, have never experienced inquiry as students and will, in turn, be unprepared to integrate it into their own teaching. This study examined an attempt by a science methods instructor to provide pre-service teachers with an inquiry experience and the opportunities to reflect on the process.

Participants varied widely in their beliefs about inquiry. The nexus of these beliefs appeared to be epistemological in nature, with some participants showing evidence of very sophisticated beliefs about inquiry and others showing less developed beliefs. Those participants who evidenced more sophisticated beliefs indicated the importance of student dialogue and helping students make sense of the inquiry process. Other participants with less sophisticated beliefs were primarily concerned with their own students being able to complete an inquiry as opposed to understanding the inquiry enterprise. Some participants with less sophisticated epistemological beliefs suggested that they would be disinclined to have their own students do independent inquiry. For many pre-service teachers, it appears that the common rhetoric about "The Scientific Method" and the ubiquitous allusions to confirmation experiences as "inquiry" in textbooks reinforces a mental model of scientific knowing that reflects neither the complex patterns of reasoning nor the tentative nature of knowledge in science.

In this study, epistemological theory and the highly-situated knowledge of pre-service teachers' interpretation of independent inquiry serve to inform each other. Epistemological theory helps to explain what individuals will see as "problematic" during inquiry, what the roles of presentation and argumentation are, and how they construe what the inquiry experience should be for their own students. In turn, the actions and interpretations of the pre-service teachers in this specific context adds to our knowledge of how epistemological beliefs can be manifested in specific learning situations.

This study does not make sweeping claims about the quality of pre-service science teachers' thinking, nor about what determines potential in future science teachers. This study does, however, identify several important links between pre-service teachers' interpretation of inquiry as a process and their plans for using independent inquiry in classrooms. Other researchers should contribute additional in-depth analyses of such inquiry experiences, but should also devote efforts to finding interventions in pre-service education that could not only give future teachers more inquiry experience, but could raise their level of epistemological sophistication as well.

It is not enough that pre-service teachers do inquiry, and not even enough that they reflect privately on their experiences. In future interventions with pre-service teachers, methods instructors should surface the epistemological beliefs of their students, make these assumptions about knowledge explicit, and help them make the connections between these beliefs and their interpretations of inquiry.

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Appendix A

Prompting questions for journal entries from the inquiry project guidelines

1. How thoroughly and insightfully have you reflected on the difference between the inquiry as a linear process and your own inquiry experiences? Is the process you went through a linear one? Why or why not? Did this change your mind about how scientists really conduct inquiry? How does this part of your inquiry make you re-think how you would design or support inquiry experiences for your own students?
2. How thoroughly and insightfully have you reflected on the experience of generating a question? What kinds of questions are you asking? Did you change your idea of what makes a good question? Why did you reject some questions? How does this part of your inquiry make you re-think how you would design or support inquiry experiences for your own students?
3. How thoroughly and insightfully have you reflected on the methods of gathering data to test your hypothesis? What kind of data did you need to test this hypothesis? Do you need an experiment or just more observations? What problems have you run into? Did you have to go back to the beginning? How does this part of your inquiry make you re-think how you would design or support inquiry experiences for your own students?
4. How thoroughly and insightfully have you reflected on the way you made inferences from your data? Was your data "any good?" Did it help you answer your question? Did you have to go back to the beginning? How does this part of your inquiry make you re-think how you would design or support inquiry experiences for your own students?
5. How thoroughly and insightfully have you reflected the experience of defending your results to a group of peers? Did defending your inquiry change the way you thought about your project? How does this part of your inquiry make you re-think how you would design or support inquiry experiences for your own students?

Appendix B

Summary of recommendations by methods students
for conducting inquiry in classroom settings

1. A general inquiry topic should be specified for the class (unless you are preparing for a science fair, or very special project) so that students can share ideas, equipment, etc. For example the topic could be microorganisms, simple machines, bodies of water, animal behavior, or velocity and acceleration, etc.
2. It is important for students to select a topic they are interested in. Inquiry requires persistence, and that is possible only if students have interest in their project. Also, many of you said you were "eager to see the results" and "excited to create your own knowledge"-- this kind of feeling comes from the combination of interest and hard

work. So even though you may identify a general area for investigation, allow students to select a question that interests them,

3. Although problems can be learning opportunities, many of you said students might begin with inquiry questions that you (as a teacher) know are real dead-ends and that would simply engender frustration in students. To avoid this, several of you came up with a great suggestion that your students give you a proposal before embarking on inquiry. In this proposal would be the question, the hypothesis, the methods for collecting the data, the method for analyzing the data, and the equipment needed to carry out the inquiry. The teacher could then (with the benefit of greater subject matter knowledge and anticipation of inquiry problems) suggest changes in the inquiry approach that would prevent catastrophic failure and loss of time. Be careful, however, because there is tremendous value in making mistakes! It remains a real art for teachers to know what kinds of "mistakes" are opportunities for learning and which ones are simply frustrating and uninformative.

4. You (as a group) alluded to the idea that problems during inquiry were opportunities to learn, and that there were plenty of opportunities! As teachers, you certainly want to make that known to your students, perhaps by letting your students read a sample log like the ones you wrote, giving them the sense that challenges and dilemmas are part of inquiry.

5. Several of you said that it was important to have some background knowledge before forming a question. Students could do some background reading to prepare for their inquiry, perhaps a summary of that reading should be in the inquiry proposal?

6. As the inquiry process gets underway, students could meet together regularly to discuss their progress. Students get a lot out of listening to the ideas of others, and making their ideas more "solid" by explaining them to others.

7. When students start doing data collection, that seems to be a time when hypotheses get re-evaluated and perhaps thrown out. When your students start collecting data, that's when you might remind them that it is OK to reject original hypotheses and make more appropriate ones.

8. Part of the inquiry experience seemed to be finding the right equipment, rigging up equipment in an unusual way, or deciding on novel ways to measure phenomena. I suppose we need to model this in classrooms and support the notion of inventiveness in inquiry.

9. Students must have a safe emotional environment in which to present their findings. Classroom norms must be developed in which positive critique is offered and people feel secure about voicing their opinions. Several of you suggested that breaking into smaller, less formal groups for presentation was a good idea. The atmosphere may be less threatening.

10. When presenting the posters, one of you suggested that the posters from the first project of the year be put on display but not defended publicly. The students might present a written defense but not an oral one. Through the year, students would gradually move to the oral defense in a public forum.

11. Many of you mentioned that you were able to work with your inquiry project because of access you had to equipment or people with special resources. As teachers, we need to constantly be making professional connections with other teachers, industry people, and university faculty. We also need to constantly be on the lookout for material and informational resources.

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