Folk Theories of “Inquiry”: How Preservice Teachers Reproduce the Discourse and Practices of an Atheoretical Scientific Method

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Abstract: Despite the ubiquity of the term “inquiry” in science education literature, little is known about how teachers conceptualize inquiry, how these conceptions are formed and reinforced, how they relate to work done by scientists, and if these ideas about inquiry are translated into classroom practice. This is a multicase study in which 14 preservice secondary science teachers developed their own empirical investigations—from formulating questions to defending results in front of peers. Findings indicate that participants shared a tacit framework of what it means to “do science” which shaped their investigations and influenced reflections on their inquiries. Some facets of the participants’ shared model were congruent with authentic inquiry; however, the most consistent assumptions were misrepresentations of fundamental aspects of science: for example, that a hypothesis functions as a guess about an outcome, but is not necessarily part of a larger explanatory system; that background knowledge may be used to provide ideas about what to study, but this knowledge is not in the form of a theory or other model; and that theory is an optional tool one might use at the end of a study to help explain results. These ideas appear consistent with a “folk theory” of doing science that is promoted subtly, but pervasively, in textbooks, through the media, and by members of the science education community themselves. Finally, although all participants held degrees in science, the participants who eventually used inquiry in their own classrooms were those who had significant research experiences in careers or postsecondary study and greater science-content background. © 2004 Wiley Periodicals, Inc. J Res Sci Teach 41: 481–512, 2004

The current rhetoric of reform in science education has been crafted to draw teachers away from an exclusive pedagogical emphasis on content knowledge and to align instruction more with problem solving and inquiry—activities which characterize the pursuits of scientists (see American Association for the Advancement of Science, 1993; National Research Council, 1996; National Science Teachers Association, 1995). Incorporating such authentic activities means that learners must assume new, more active roles in the classrooms—first those of apprentices, then later as legitimate participants in the canonical practices of science. This vision, however, is based on the assumption that within the science education community there is a shared, if not explicit,
notion of what these disciplinary practices entail. It is further assumed that individual teachers have developed functional models of what it means to “do science” and are capable and willing to act as mentors of inquiry. Unfortunately, none of these assumptions is well-grounded, and the negative impact on how learners come to understand science cannot be overstated.

This study examines models of inquiry that are shared by preservice teachers and reinforced by various discourses in the science education community. I draw upon the idea of “folk theory,” taken from the field of cognitive anthropology, to ground participants’ conceptualizations of inquiry in this broader cultural context. Discourse, in this study, includes not only how language is used to engage in meaningful activities but also how people integrate language with thinking, acting, valuing, and using tools and conceptual frameworks to accomplish certain aims.

Using the Idea of “Folk Theories” to Understand the Inquiry Practices of Preservice Teachers

This analysis is based on the theoretical construct of folk theories\(^1\) (Boudon, 1986; D’Andrade, 1995), also known as cultural models (D’Andrade & Strauss, 1992; Holland & Quinn, 1987; Shore, 1996). Folk theories are presupposed, taken-for-granted theories about the world that are widely shared by most members of a society (although not to the exclusion of alternative models) and play an enormous role in individuals’ understandings of the world and their behavior in it (Holland & Quinn, 1987). In everyday life people form, transform, and operate on “theories” of common ideas such as “bachelorhood,” “going shopping,” or “patriotism.” Take, as an example by Mitchell (1990, described in Gee, Michaels, & O’Connor, 1992, p. 238), a teacher of a college English as a Second Language (ESL) composition class. This teacher held to a folk theory that composition ought to be a “discipline” and that disciplines have their characteristic textbooks that define the boundaries of knowledge for which the discipline is responsible. The teacher took the Little Brown College Composition Handbook (1989) to be such a disciplinary text and saw it as her responsibility to teach its “content.” She was teaching, however, in a process-oriented writing program which was intended to downplay teacher authority in an attempt to foster student voice and empowerment. Her theory, much of it tacit, influenced her participation in the activity systems of both the classroom and the college.

Such personal theories, models, or everyday explanations are largely subconscious, or at least not easily articulated in full detail, and are often incomplete. Some aspects of these folk theories reside in individuals’ heads while others are shared across members of a community, across texts and other media, and are embodied in various social and educational practices (Hutchins, 1995; Shore, 1996). According to Holland and Quinn (1987), from a pragmatic standpoint, folk theories help people to:

... make sense of actions, fathom the goals of others, set goals for action, plan for attainment of goals, direct actualization of these goals, and produce verbalizations that may play parts in all the aforementioned projects as well as in interpretation of what has happened. (p. 37)

Furthermore, institutions create forces (authoritative documents, apprenticeships, sanctions, and rewards) that ensure repetition and ritualization of many folk theories and the situations that sustain them.

Just as there are folk theories for ideas such as what it means to “be a discipline,” there also are folk theories associated with science education. The idea of inquiry—the quintessential scientific endeavor—is arguably the most important subject of folk theory. The folk theory that
goes with inquiry (as practiced by scientists) includes the idea that people conduct inquiries to “find something out,” but that there are different forms of scientific 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. Just as with other folk theories, the meaning of science inquiry does not reside in any dictionary and cannot be reduced to symbolic representations in people’s minds. Rather, it is situated in specific cultural and disciplinary practices and is continually transformed through these practices. Every day, thousands of science teachers enact their favored models of scientific investigations and, in doing so, reinforce various dimensions of a folk theory of inquiry (or “doing science”) as they plan classroom lessons, interact with colleagues, adopt textbooks, talk about their work at conferences, host science fairs, draft local standards for learning, write about their practice for publication, and supervise beginning teachers.

Classroom inquiry has been associated with a wide range of intellectual activities, including hypothesis testing, practical problem solving, modeling, thought experiments, library research, and engaging in Socratic dialogue. It has been equated with hands-on activities, discovery learning, and projects. Of these activities, hypothesis testing is perhaps most closely associated with inquiry, due to its place within the virtual institution of the “Scientific Method.” The Scientific Method (making observations, developing a question, constructing hypotheses, experimenting, analyzing data, drawing conclusions) is often portrayed in textbooks as a linear procedure; however, this characterization and even the label itself are misrepresentations. 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, investigative design, data collection, and analysis are mutually interdependent considerations. The simplicity of the Scientific Method obscures the complex methodological strategies (e.g., developing laboratory situations analogous to real-world conditions), and involved logic (e.g., coordinating theoretical models with multiple sets of multifaceted, partially conflicting data) of authentic science. Furthermore, 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; however, other scientists 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, 1999).

In contrast to the explicit protocol of the Scientific Method, the broader concept of “inquiry” has had less well-defined contours in classroom practice. As with all folk theories, ideas about inquiry are partly “in the head” (with different people understanding different aspects), partly embodied in the practices of the classroom, and partly codified in various community-wide discourses. Some of this discourse is enacted through official documents such as Inquiry and the National Science Education Standards (National Research Council, 2000) or Benchmarks for Scientific Literacy (American Association for the Advancement of Science, 1993), which offer guiding principles for classroom investigations and prototypical examples of inquiry.

Another component of public discourse about inquiry is the science textbook, which often uses the term “inquiry” in arbitrary ways. In one teachers’ edition of a popular physical science text (McLaughlin & Thompson, 1999), pages are occasionally marked with problems labeled “Inquiry Questions” for students. Many of these, however, require no more than one- or two-step algorithms to solve a basic mathematical problem that has no obvious connection with scientific phenomena. For example, one such question asks: “Early cartoons required 16 drawings for each
second of action, how many sketches would be required to make a five-minute cartoon?” (p. 11). Even when textbooks describe inquiry as investigations, these bear little resemblance to authentic science. Chinn and Malhotra (2002) examined 468 inquiry tasks in nine textbooks written for upper elementary and middle schools; none of the activities required students to develop their own questions, only 2% of these activities required students to select their own variables, and there were few opportunities to think about controlling variables. These results are similar to those from an analysis of 90 high-school texts by Germann, Haskins, and Auls (1996).

Science curricula, especially those that are widely adopted, also can reinforce particular images of inquiry. The National Curriculum for England and Wales, for example, portrays inquiry as multiple variable problems where students identify which independent variable affects a given dependent variable in a range of physical and biological contexts (Driver, Leach, Millar, & Scott, 1996). This view of scientific investigation ignores theoretical models and fails to portray the much wider variety of forms of inquiry scientists undertake.

There are still other kinds of public discourse which influence how people make sense of, enact, and reproduce certain forms of pedagogical inquiry. A recent broadcast by National Public Radio (2002) told the story of a high-school biology class that had adopted an inquiry approach to learning. The segment opened with the sounds of students’ voices as they roamed the halls of their school with cotton swabs and petri dishes testing different surfaces for bacteria. One student remarked that they were “doing a different activity every day” (suggesting that at least some inquiries can take place in the course of one class period). The radio story then cut to the teacher who asserted that inquiry was “allowing students to ask their own questions and giving them the tools to find their own answers.” A few moments later, however, a second biology teacher in the school is asked for her opinion; she describes her more traditional instructional philosophy and cites key contrasts with the featured inquiry approach of her colleague. As the story unfolds, inquiry (as opposed to didactic methods) is characterized by the first teacher as a “thinking rather than a memorizing” approach. The second, more traditional colleague, questions the whole notion of “slipping content into inquiry” and claims that content in an inquiry classroom is only addressed when it is “disguised as essays” during assessments. The point of the story seems to be about irreconcilable differences between inquiry instruction and direct teaching methods— inquiry is left characterized as activity rich, but lacking in content.

The previous examples are not meant to be part of an in-depth analysis of cultural discourse around inquiry teaching; rather, they provide evidence that different ideas about inquiry exist not only “in the heads” of science teachers, but are codified in authoritative documents, reinforced by textbooks, broadcast in the media, and embodied in the practices of educators who promote the use of inquiry as well as those who favor more traditional methods.

Inquiry Experiences and Preservice Teachers

Preservice teachers develop a host of ideas about doing science, constructed over years of schooling, and prepare themselves to continue various aspects of this legacy with their own students. The most recent and most involved of these science experiences often come from their years as undergraduates. What then is the model of inquiry that preservice science teachers are exposed to in college 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 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, preservice 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).

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, Klopfer, Aikenhead, & Robinson, 1981). Studies of inquiry in teacher education programs indicate that preservice teachers 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.

Involving preservice teachers in inquiry experiences, however, may not be enough to develop their conceptions of inquiry or their disposition to use it in the classroom. For example, in studies on inquiry projects with preservice science teachers, Windschitl (2001, 2002) found that the experience refined the inquiry conceptions of those participants who already had more sophisticated understanding of scientific investigations. Participants with simplistic notions of inquiry (based on their image of a one-dimensional Scientific Method) seemed to do little more than confirm these beliefs through the course of investigative activity. 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.

Purpose of the Study

From a constructivist perspective, the only way to influence the eventual practice of beginning teachers is to first understand how educational and broader cultural experiences have shaped their thinking about scientific inquiry. And, because terms such as “inquiry” derive meaning from the context of their use, an effective way to reveal the existing understandings of participants is to have them perform and reflect upon their own empirical investigations. This study has two distinct, but related, parts. *Part I* is an examination of how preservice teachers reference folk theories of “inquiry” within independent investigative experiences. The research questions are:

1. How is the idea of science inquiry being constructed (or reconstructed) by preservice teachers?
2. What folk theories are being invoked in this situation, and how are they being stabilized or transformed in the process?
3. What are preservice teachers’ emerging models of pedagogical inquiry as they project how their future students will participate in “doing science?”

*Part II* of the study examined the use of inquiry instruction by participants during their student teaching. One question was investigated:

4. What conceptions of and experiences with inquiry are linked with preservice teachers’ use of inquiry in their own classrooms?
Participants

The 14 participants in this study were students in a teacher education program at a public university in the northwestern United States and enrolled in a secondary science-methods course. The teacher education program at this institution is relatively small and dedicated to producing graduates who will assume leadership roles in their schools as well as become exemplary classroom teachers. All candidates enter with a bachelor’s degree in some area of science and graduate with a master’s degree in teaching. Many of these preservice teachers have prior work experience in the science or technology fields. The methods course included explorations of the nature of science, goals and objectives in teaching, lesson planning, unit planning, laboratory work, inquiry, 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 13 years of experience in various forms of inquiry-based instruction.

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 to find 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 perspectives were voiced by 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; however, most students were unable to articulate a coherent model of inquiry.

The rationale for the inquiry project originates from the fact that despite taking dozens of science courses, participants had little experience with inquiry. In fact, in methods courses taught by the author over the previous 4 years, when students were asked whether they had in any science class (K–16) generated their own question for investigation and designed an investigation to resolve the question, only about 20% said that they had ever conducted independent inquiry—at any level of science education. Of this small percentage, all reported that they engaged in only one or two such inquiry activities. Another reason for the inquiry project is that science learners (in this case, preservice teachers) need to engage firsthand with the full complexity of scientific investigations to understand the epistemological challenges of coordinating theory, questions, data, and conclusions; only in such immersive activity will they confront the dilemmas, contradictions, and ambiguities associated with canonical approaches to knowing the natural world. If they are to mentor their own students through inquiry, they must feel some intellectual and methodological competence, gained not through reading or hypothetical discussions but through firsthand experience and reflection on that experience. Participants in this methods course had the opportunity to engage in goal-oriented dialogue about inquiry, situated in experience—not only theirs but that of their colleagues as well. The methods course allowed the instructor to scaffold the inquiry-oriented thinking of the participants while providing a forum for discussions of how participants could scaffold the inquiry experiences of their future students.
The methods students, then, were asked to engage in an independent inquiry as a course project. They 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 another 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 8 weeks to complete their work. The students’ research encompassed a range of interests including friction in bicycle wheels, the differential expansion and contraction of freezing liquids, the growth of mold on food, the feeding habits of birds, and a variety of other investigations.

The Reflective Journal

To capture students’ ideas generated throughout the inquiry and make these ideas explicit objects of reflection, they were asked to maintain a journal. 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 a parallel record maintained; participants were asked to describe how these experiences were informing their consideration 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. The journal was a way to externalize self-dialogue about the inquiry, which would normally be internal and poorly articulated, and to document this dialogue in a sharable artifact.

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 and began their work on the project at the end of that week. From Weeks 2 through 9 of the course, a number of topics, not directly related to inquiry, were addressed. However, students were given 30 min every other class period to discuss their ongoing inquiries in small groups. 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 faced in collecting data.

During Week 7, students were introduced to inquiry as an instructional approach. 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 (a) use background information to help think about a natural phenomena in terms of models, (b) scaffold learners’ understandings of the difference between observations and inferences, (c) categorize questions that learners might have about earthworms, and (d) help learners transform some of these “everyday” questions into researchable questions. During the next class session, students agreed to one question on 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-group 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. During Week 9, the class explored together how a teacher could help students construct scientifically valid arguments based on data, prepare for presentations to their peers, and negotiate the kinds of questions students could be asked during presentations. During Week 10, students presented their inquiry results.

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 procedures, thoughts, and feelings about the inquiry process, and the implications of these experiences for the design of inquiry activities with their future students. After the final presentations at the end of the quarter, students were interviewed about their personal history with inquiry in science classes from middle school through undergraduate studies, and about experiences with inquiry/research in their professional careers. They also were asked for additional reflections on 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 their school placements the following fall quarter. The field supervisors were former secondary science teachers with approximately 10 years of experience each. One of two supervisors observed each of the students

<table>
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<th>Week</th>
<th>Selected Activities Complementing the Inquiry Project</th>
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| 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.
multiple times each week for 9 weeks at the beginning of the following school year. While each participant had responsibility for designing and implementing the curriculum in their respective classrooms during this time, it should be noted that cooperating teachers most likely had some influence on the instructional strategies chosen by the participants. Consideration of these influences were not included in this study.

Data Sources/Analysis

The initial phase of analysis of the journal and interview data was based on Gee’s (1999) notion of “building tasks.” The premise is that any sample of language is composed of a set of cues that helps listeners or readers understand how the authors (the participants) are attempting to build various representations. These tasks are carried out in collaboration with listeners or readers, with due regard for related oral and written discourses and situations (sociocultural knowledge) they have encountered before. Two types of building tasks are relevant to this analysis. The first task is “activity building.” The initial questions asked of the data were:

- What activity or sets of activities are going on in this situation?
- What subactivities comprise this work?

The second task is “world building.” The relevant questions were:

- What folk theories seem to be at play in this text?
- What institutions are being reproduced in this situation and how are they being stabilized or transformed in the act? (Gee, 1999, pp. 92–94)

These questions were applied to the text of the journals and served to focus the development of tentative hypotheses. The interview data were then used to confirm/disconfirm developing hypotheses from the journals about the three research questions in Part I of the study. In particular, participants were asked about inquiry experiences in their education (K–16) and their experiences (if any) with science-related research in their careers. They were asked to describe guided or independent inquiry experiences in high school or college. Participants’ responses 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. Some inquiry experiences also included career work in various scientific or technical fields. These ranged from working as a lab technician who performed data collection and analysis protocols to more involved membership on research teams participating in authentic problem posing, research design, and data analysis.

A more normative approach was used to answer the final research question. From the interview data, participants’ investigative experiences 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 schooling (K–16), in a science setting after graduation, or both. This included work in science settings which was restricted to performing technical tasks (i.e., collecting and analyzing data, following protocols designed by others). These individuals were not involved in the posing of research questions or in research design. Those who were rated “Low” reported no instances of independent or guided inquiry throughout their schooling (K–16), very few instances of structured inquiry during school, and no work-related experiences involving research.
Finally, data were collected in the field by two supervisors who observed the student teachers in classrooms for 9 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 stayed for two class periods. They 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 teacher- or student-centered along five dimensions. For this, the supervisors used an observation instrument derived from a table in the National Research Council’s (2000) publication, *Inquiry and the National Science Education Standards* (p. 29, see Appendix A). The field supervisors also asked participants what types of instructional activities they had used with students since their previous visit.

**Results**

**Part I**

*Reproducing Limited Folk Theories of Inquiry.* All journals exhibited a similar macrostructure (highest level of textual organization). Two patterns were clear from this perspective. First, even with substantial science backgrounds, participants found the planning and execution of an independent inquiry much more difficult than they had anticipated. Second, these challenges directly influenced how they considered using inquiry with their own students. The following sequence appeared with only minor variations in all participants’ journals:

1. Participants describe unexpected difficulty developing their own inquiry question. Many felt “overwhelmed” and took more than 2 weeks to develop a suitable question.
   1a. *Reflection on students:* Participants then ask, in a variety of ways, “How could my students deal with developing their own questions?” Participants wrote about ways to assist future students in developing questions; some suggested independent inquiry was impossible with students.
2. Participants describe unexpected difficulties designing the study; they have troubles with operationalizing variables, identifying controls, etc.
   2a. *Reprise about students I:* Participants again ask, “How could we help students do this? Is it possible?” Participants consider strategies to reduce the complexity of open inquiry for their future students.
3. Participants execute study and describe setbacks; many “go back to the drawing board” as they encounter difficulty in securing equipment to do their studies, discover that they had not adequately defined phenomena under investigation, failed to adequately specify how they were to collect data, and some realized that their initial questions were moot.
   3a. *Reprise about students II:* Participants return again to the theme, “How can students deal with this complexity?” They conclude: “Doing real science includes making mistakes.” (Steps 3 and 3a were repeated several times in most cases.)
4. Project culmination, presentation to peers, reflection.

Applying the notion of “building tasks” to the inquiry work of the participants, I tried to understand what kinds of activities and subactivities were part of these accounts of inquiry and whether a shared folk theory of inquiry was supported by the data. From the journals and interview data, it became clear that participants took “science inquiry” to be more than posing and finding
an answer to a question. Across participants, there were similar implicit dimensions of inquiry that guided their actions and shaped their reflections. Some facets described by participants were congruent with authentic science inquiry:

- Empirical inquiries involve developing testable questions about natural phenomena, designing studies, and collecting and analyzing data;
- decisions related to each phase of inquiry are contingent upon and interrelated with other phases (e.g., the design of data-collection procedures must refer back to the variables and their relationships stated in the hypothesis while taking into account the anticipated methods of data analysis);
- multiple data points are necessary to make claims about differences between two or more comparison groups;
- authentic inquiry often involves altering the question or the design of the study after the study begins;
- logistical and methodological setbacks are to be expected; and
- the lack of conclusive results or results that run counter to the original hypothesis cannot be considered a failure.

At the same time, other facets seemed to represent a limited view of scientific inquiry:

- There is a “scientific method,” although it is not linear;
- controlled experimentation is synonymous with inquiry; and
- comparisons between experimental conditions determine the answer to the inquiry question; however, statistical tests of significance are not part of inquiry.

And, several facets were misrepresentations of some of the most fundamental aspects of scientific inquiry:

- Hypotheses function as guesses about outcomes, but are 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 or tentative scientific model;
- theory is an optional tool you might use at the end of a study to help explain results; and
- the ultimate goal of inquiry is to determine whether a relationship exists between two variables.

Absent almost entirely from participants’ accounts was talk about claims being supported by argument, consideration of alternative explanations for results, and the kind of discourse generally related to the epistemological bases of inquiry.

Perhaps the most problematic shortcoming in the versions of inquiry used/constructed by participants was the absence of theory or scientific models in their investigations. This was evident in the journaling and interviews of almost all participants. In general, they did not make the methodological connection that investigations should be based on some explanatory premise nor was there evidence that they understood that the goal of inquiry is to support, revise, or refute various aspects of scientific models. For example, the absence of theory or even any background information to guide the development of hypotheses was characterized by participants’ initial brainstorming about questions and selecting what seemed 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.... We went toward having the plants in containers and exposing them to different types of air pollution. What about cigarette smoke? Fire smoke? And carbon monoxide even!

A third participant, Jenelle, had an extensive background in chemistry and may have had an implicit scientific model in mind, but her journal entry seemed to suggest a “try something and see what happens” orientation. She wrote: “We’re just going to bubble [car] exhaust through water and see how acidic it gets over time.”

To contextualize claims made to this point about the various facets of a common folk theory of inquiry, the cases of 3 participants will be described in depth. One of these participants had significant research experience; the other 2 participants had undergraduate degrees in science, but no experiences with research or conducting their own inquiries. Although all 14 participants appeared to invoke similar mental models of inquiry to conceptualize their projects, there were some differences between those who had previous research experience and those who had little or none.

*Carmen—Theorizing in Hindsight.* Carmen was an intelligent, articulate preservice teacher who was open to revising her ideas about science as a discipline and about science instruction. She entered the teacher education program with a bachelor’s degree in geology. In the 2 years between graduating and entering the teacher education program, she had no experiences in research settings. As an undergraduate, she had neither participated in authentic forms of scientific inquiry in classes nor worked in any laboratory settings. In an interview, she recalled:

Everything in college and in high-school chemistry—everything— was handed to us with a procedure and materials and a purpose for doing it all laid out like a cookbook. In college it was the same thing in a lab book, and it was all laid down. We never actually had to or got to pursue our own questions or make up our own hypotheses or devise how we would run the experiment.

For her inquiry project, Carmen chose to work with a partner, Michael. In considering a question, Carmen first thought of activities that were not studies of hypothesized relationships in natural phenomena. She wrote early in her journal: “One of my ideas is to determine how accurate the weather person is and how weather is predicted, or how a clock powered by fruit works.” She finally settled on using different types of fertilizers on plants to see which ones would cause plants to grow faster. Her hypothesis, however, was not grounded in any scientific model: “I hypothesize that Green-Gro would work the best. The reason for my hypothesis is that since chemical fertilizers are produced and used quite commonly, they would be somewhat better than organic fertilizers.”

In executing her study, Carmen’s inexperience with research became evident. For example, she did not anticipate having to standardize the measurements in her study: “Now that the plants are getting taller, I am worried that Michael and I have been measuring the plants differently.” She eventually had to sketch out for her partner how to measure the plants. This confusion was due, in part, to not operationally defining key variables in the study. In her journal, she recounted a classroom discussion in the methods class during which she described her study to colleagues:
I told the class that our hypothesis was that Green-Gro, a chemical fertilizer, would promote plant growth. Everyone wanted to know what I meant by “promote plant growth.” I wasn’t sure myself! I became very worried and confused about what my hypothesis is! What did we mean?

And 2 days later,

In class we went over the operational definition of terms that we should be applying to our projects. I had never heard of “operational definitions” and was completely confused what it means.

During class, Carmen also learned that her results could be statistically analyzed for significant differences:

I had never taken a statistics class and I was unsure if statistical analysis could be applied to our project. I explained our experiment to [the author]... he said that chi-square is a statistical method that is applicable to our experiment. I had no idea what this method entails!

In addition to having difficulties in operationalizing key terms and using statistics, Carmen also had trouble grasping the difference between increasing sample size and creating multiple experimental groups. She had been using chemical versus organic fertilizer on three different types of plants. She explained:

I talked with an engineering friend of mine last night about my hypothesis. My friend suggested that the experiment was actually three experiments. Three experiments? My friend and I talked it over, and it was true, we did run three separate experiments—how chemical and fish fertilizer effect corn plant growth, how chemical and fish fertilizer effect bean plant growth, and finally, how chemical and fish fertilizer effect pea plant growth. It didn’t seem right to have only one hypothesis for three experiments... I thought we were just increasing the sample size.

In response to her own missteps with experimental design and measurement, she wrote about how she would support her own students with inquiry, but she did so only in the most general terms:

While engaging in inquiry, problems arise that require inventive problem-solving skills... As a teacher, I want to incorporate statistical analysis into the classroom. I also find it valuable to teach students to operationally define terms that they use in their projects... This would serve students in realizing what it is they are actually measuring.

At the very end of her project (1 day before the final presentation), Carmen became interested in the science underlying the phenomena of plant growth and fertilizers. She used the Internet to find the composition of “Green-Gro” and the composition of the organic fertilizers she had used. In her journal, she then constructed—without referring to “theories” or “models”—her own model of fertilizers’ effects on plants, based on this background information and logic:

It appears that the Green-Gro has more “stuff” in it [nitrogen in various forms] so why wouldn’t it do better? Why is a chemical fertilizer said to be better for the environment?... I did some research on the Internet at home. Here is a list of key information I found on the Internet that apply to our project: Nitrogen, phosphorous, and potassium are principal plant nutrients. Organic fertilizers are naturally occurring, in our
case fish fertilizer is from ground up fish that contains organic nitrogen. Chemical fertilizers are made from raw materials that are changed into a form readily usable by plants. The nitrate and urea nitrogen in Green-Gro are highly soluble, they are a major source of groundwater pollution. They are highly leachable and move readily with water into the soil. Since organic fertilizers need to be converted, it is more “time-release” and acts slower.

Carmen had initially developed her research question and designed her study without reference to any scientific model, yet at the very end of the project—perhaps out of pure curiosity—she successfully made sense of the inquiry experience by placing it within the context of a causal model of chemical and biological phenomena (Recall that her hypothesis was “since chemical fertilizers are produced and used quite commonly, they would be better than organic fertilizers.”)

After Carmen had presented her findings to colleagues, she confronted her own inexperience with inquiry and the hidden complexities in what she had thought was a straightforward process:

I have never had to devise my own hypothesis and I never realized the details. I think the reason I was so nervous about our hypothesis is that a hypothesis is such a fundamental principle in science and I feel that I should have noticed that we were actually running three different experiments in the beginning . . . Only when students work through the confusions and frustrations will they construct deeper meaning for what science entails. Students are more likely to develop a genuine conceptual understanding about the concepts involved in their project and the scientific method by engaging in the inquiry process.

Despite several major shortcomings in her inquiry design and execution, Carmen recalled in the interview that the inquiry went smoothly and only indirectly mentioned “experimental errors.”

I think ours went pretty smoothly. Michael and I both thought up our questions and then we met together and decided on a question that we both liked . . . there were a lot of experimental errors in it as well, which I thought was kind of a valuable thing to teach my students . . . I think that’s a good part of being a scientist in realizing your errors and how to fix it. A lot of our errors were like, we didn’t measure the depth, all the seeds weren’t planted at the same depth, we didn’t pot the plants at the same time because we ran out of soil, we didn’t water the plants at the same time. So any huge problems? Well, we didn’t run into anything huge, other than the experimental error. All of our plants grew pretty well.

Thus, despite difficulties with operationalizing key variables and several compromises with methodology, Carmen felt satisfied with how her inquiry unfolded.

Erica—Images of Inquiry as Scientific Method. Erica was a thoughtful and enthusiastic preservice teacher who valued a student-centered approach to instruction. During the methods course, she consistently made connections between theory and practice, and related what she was learning in the class with teaching practices she observed in the schools. As an undergraduate, Erica had assisted in running psychology experiments for a professor, but had “only run subjects through protocols” and was not 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:
... 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.

For her methods class project, Erica worked with a partner, Amanda. Over the first 3 days of her journaling, Erica recorded the following attempts to identify a research question:

- 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.

Erica did not consider how detergents or cigarette smoke might affect plant growth, and her journal entries did not indicate that she used theory or any explanatory framework to guide her thinking. She seemed focused on an inquiry model of “comparing conditions.” Erica finally decided on investigating plant growth in different detergent solutions and then moved on to consider her experimental setup. She and her partner created four groups of plants to be grown in various solutions: water with Clorox, floor cleaner, dish soap, and environmentally safe kitchen cleaner (She did not create a control group.) She placed four plants in each condition and monitored their growth. 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.

Erica had apparently made a methodological connection between the development of the question and the investigative design, but did not make the equally important connections between the question and a tentative explanatory framework for the phenomena of interest.

The lack of connection with theory seemed to be the reason for her eventually being surprised by the plants’ growth. About 6 weeks into the experiment she recorded: “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 her hypothesis was “correct;” however, her hypothesis was simply that there was going to be a significant difference between experimental groups. It was not until 2 months into the experiment that Erica used some explanatory framework to guide her thinking: “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. Instead, she continued to focus “inward” on her procedure, wrestling with how to analyze and draw conclusions from her data.

As she accumulated more data on her plants, she began to incorporate ideas from class conversations into her plans for analysis. Specifically, she used the vocabulary of “evidence” and “significant differences” in her journal, but only after these ideas were introduced in a classroom discussion. She wrote in her journal:

In class we talked about evidence and how to get kids to understand that. I have a hard enough time explaining it now, clearly. I feel that evidence is information that supports or rejects a hypothesis. It has to be measurable ... The other day I was looking at the plants
and it looked as if the leaves of the plants receiving the dish soap were much smaller than the other plants. I was about to record this observation when I realized this would not be good data. It is not evidence. I need to be able to measure it in order to show that there was a difference. Furthermore, I need to have some kind of numbers to analyze if there is a significant difference or not.

Her conceptualization of a kind of self-contained scientific method, in which question did not derive from tentative scientific models and the findings did not contribute to the development or refutation of a model, was a strictly stepwise procedure for classroom inquiry and evidenced in comments about working with 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.

To Erica, however, determining “what it means” meant declaring significant differences between groups, not using findings as evidence to support explanations of scientific phenomena. In the postproject interview, Erica was asked about the role of theory in her investigation:

Interviewer: Did you use any theory in developing your own inquiry or guiding your own inquiry, did you use anything?
Erica: What do you mean?
Interviewer: Theory of—any scientific explanations.
Erica: 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 them something that interferes with that or somehow . . . . 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.

Erica was then asked if there was any difference between her inquiry and that of scientists. Her reply indicates the belief that scientists “come up with a question” as she had done, but that scientists have a clearer plan of investigation and that they are 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 . . . . I hope they’d probably put a little more thought behind, we kind of came up with question and we planted the plants 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 . . . .

When asked to consider pedagogical applications of inquiry, Erica expressed reservations about allowing open inquiry and recalled more “controlled” versions of inquiry she had seen that reinforced her ideas about simple testing:

I am not sure if there is enough time in class to involve the kids in a totally open-ended inquiry project. I think that there needs to be more structure for the kids to benefit from it. I have seen inquiry done where the students are presented with an organism and told to ask a
question about it that they can test. I have seen this done with banana slugs and slime molds. This directs the students more and I think it’s easier for them to come up with a question when they can look at an organism. Before an inquiry experiment students need to learn about hypotheses and other aspects of the scientific method and have some practice using it in a more structured setup.

Finally, and coincidentally, toward the end of the fall quarter, Erica visited a sixth-grade classroom where students were experimenting with plants and designing inquiries in much the same way that she had. This was one of the final entries in her journal:

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 idea 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.

Rachel—The Simple Inquiry Project that Wasn’t. Rachel entered the teacher education program with a PhD in Pharmacology and had done a number of independent research projects during her graduate studies. In the methods class, Rachel used her considerable research experience and content knowledge to add unique disciplinary perspectives to class discussions. She was looked upon by her classmates as a “real scientist” and a helpful colleague. Her project for the methods course was to test conditions that encouraged mold growth in bread.

Rachel indicated during the interview that she was already a knowledgeable researcher, stating “all of my graduate work is completely independent, coming up with projects on your own, directions your own . . . so I’ve been through a lot.” In her journal, she wrote:

When we were given the assignment, I saw that it would be valuable for my classmates, but I did not think that I would get much out of it. This is because I have been doing independent inquiry for a long time in my life as a graduate student in science. I thought that I knew everything that my classmates would come to know through this process.

Rachel’s familiarity with research led her to ask key questions at the outset of her project that less experienced participants failed to consider. For example, early in her journal entries as she settled on a general topic of investigation, Rachel tried to clarify for herself what the purpose of her experiment was and how the design would unfold:

I keep running into difficulty regarding the overall point of the experiment. Is it to see under what conditions we observe the fastest mold growth? Is it to tally the different kinds of mold, fungi, etc. which grow? Would we be able to devise a clear way to take measurements that would adequately answer our question?

In contrast to Erica and Carmen, who used no apparent scientific model to help frame their questions, investigation, or conclusions, Rachel’s journal entries suggested that she was using some kind of model, albeit implicit, to guide her experiment. During the early weeks of her investigation, she mentioned several causal relationships regarding mold growth and environmental conditions:
“Our hypothesis is that increased moisture, temperature, and lack of preservatives will increase mold growth.”
“‘I was able to modify my questions knowing that both temperature and moisture were important.’”
“‘I set up the second experiment with the same assumptions that preservative-containing bread fosters slower growth.’”
“‘I wondered if salt might act as a preservative.’”
“‘I assume that the only difference between them was preservative content. Instead, I cannot be assured that pH, moisture content, quality of ingredients and baking procedure were not different as well.’”

Even as Rachel faced her own investigative challenges, she did not suggest that independent inquiry was impractical for secondary students. Rather, she used both her past experience with research and her current experimental dilemmas to outline a number of scaffolds for students attempting inquiry:

- “Even if students were working independently, I would have them form groups for talking through the question process. I would also use group or peer review for advice during the experimental design, data analysis, and conclusions.”
- “I would want students to be able to go through some hypothetical scenarios based on their questions to see if they would be satisfied with possible answers. For example, with this mold growth experiment—how would I measure mold growth? . . . Is it to tally the different types of mold, fungi, etc.? Am I looking for the number of colonies? The size of mold colonies?”
- “I would want students to go through some hypothetical scenarios based on their questions to see if they would be satisfied with possible answers.”
- “It’s very important to stress that they should write down all observations during an experiment because something apart from the standard data collection might be the most important result from the experiment.”

As her own investigation progressed, Rachel seemed to emphasize the procedural and prescribed aspects of doing science in her future classroom. She wrote these comments: “I don’t think that students should think that inquiry is a free-for-all.” “I think that it is more important to work on getting a good, testable question, rather than pushing for the creative ‘I thought it up on my own’ mentality.” “A person should be able to come in and duplicate their results using methods that they devise. Therefore the methods should be well-defined.” Soon, however, unexpected problems with her study prompted a change in her journal entries. Rachel encountered complications in what she had considered to be a simple investigation (e.g., not realizing that bread in sealed containers already had mold spores on them, not realizing that bread laid out on open counters would become too dry to support mold growth, incorporating too many variables in one experimental design, and failing to think objectively about the relationship between her data and her conclusions—she had tried to “fit” the data to match her hypothesis). She found herself having to throw out her original data and redesign her experiment. This prompted her to equivocate earlier assertions about the importance of structured procedure. She added these three passages to her journal:

- “Students need to know that inquiry is not necessarily a linear process. A scientist is allowed to modify their question and hypotheses and can change their experimental set-up in order to do this.”
- “I would want students to come up with questions that could be tested in a variety of ways and that could be modified as data started to come in. Students need to be given time to extend and modify their inquiry projects.”
• “[Students] might never learn that this is an exploration of ideas. They are not following a road map. Instead, it’s okay to get lost and take a longer route to get to the endpoint.”

As her project came to a close, Rachel began to view herself as “the scientist who should have known better.” She made what she considered several methodological mistakes and felt that she failed to think critically about key aspects of her study. During her postproject interview, she lamented: “When I started the project, I thought ‘how simplistic this is going to be!’ And I made all these horrendous, what I would consider mistakes, because I should know better . . . and I’m like “Oh man, I did this again!” She labeled her final journal entry “a really honest reflection:”

...I am chagrined that knowing about how to do a good inquiry did not translate into my actually doing one. I made classic mistakes in experimental set-up, design, data collection and data analysis. Some of these are due to my own bad habits. However, I made other mistakes as well. The biggest was that I knew the answer to my inquiry project before I began it. This led me down the classic path of having a narrow vision of what the data meant. And so, I end this journal still thinking about the very simple inquiry project that wasn’t.

Participants’ Ideas about Supporting Future Students in Inquiry. As participants struggled with unexpected procedural and logistical challenges, these episodes shaped their thinking about strategies they felt they would have to employ with their own students. These strategies for instructional support were of three types, ranging from more teacher controlled to more student centered. Most participants mentioned at least two of these three general strategies in their journaling. These were:

1. Providing direct instruction on procedures and skills used in inquiry (However, no participants mentioned that the teacher should offer background content for the inquiry nor did they mention the use of potential scientific models that could contribute to students’ inquiries.)
2. Adding more structure to the inquiry process (giving students a 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)
3. Using scaffolding techniques based on sense-making activities by students and the use of peer dialogue as a way to support learning

One participant, Amanda, connected challenges she experienced during the inquiry project with the gradual reevaluation of the possibility of doing classroom inquiry. She had teamed with Erica to do the plant experiments using various cleaning solutions (described previously). As Amanda, over time, felt increasingly challenged by her own project, her writing about classroom inquiry shifted from ideas about scaffolding to ideas centered on control and finally to suggestions of abandoning independent inquiry as a teaching strategy. She began by reflecting on ways she might scaffold students’ understanding of data collection and analysis—strategies based mostly on sense-making activities prompted by the teacher.

What data would help us discern if the chemicals had an effect on the plants? If I wanted to help my students discover what data is relevant, 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 facilitate inquiry learning in the 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. 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’s talk about pedagogical strategies shifted from sense-making approaches to techniques that were more about controlling the number of options that students would have to keep them from getting, as she put it, “lost in science:”

. . . 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. 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.

Near the end of her journaling, Amanda eventually differentiated inquiry into “projects” and “activities” as a way to further reduce the complexity of classroom investigations 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
Not all participants’ writing exhibited such clear shifts from sense-making strategies to more overt teacher guidance. What was clear from all 14 cases, however, was that participants’ accounts of unexpected challenges with their own inquiries were directly linked with their writing about strategies for scaffolding or more teacher control. Similarly, all participants at some point in their journals questioned the feasibility of doing unguided independent inquiry with their students.

Part II

Using Inquiry during Student Teaching. This section attempts to answer the question, “What conceptions and investigative experiences are linked with preservice teachers’ use of inquiry in the classroom?” The data indicate that teachers’ previous research experiences are linked with their use of inquiry activities in classrooms. Figure 2 shows, for example, that David, who had done several research studies in a previous career, used guided inquiry in his student teaching. He provided a question for his students: “Does saliva break down starches into sugars?” and asked them to design and complete an investigation to answer it. Likewise, Amanda, who as an undergraduate had done a quarter-long study of frog behavior at a local zoo, used guided inquiry extensively in her classroom. She scaffolded her students’ inquiry skills by guiding them through a whole-class inquiry on surface tension in liquids, then had them select a variable to change and conduct the resulting study on their own. By contrast, participants who had little or no research experience (Carmen, Nick, Jenelle, Bria) used occasional discovery activities or confirmation labs, but with the exception of Carmen, who used guided inquiry once, none used any forms of inquiry.

One notable “outlier” in this data was Joanne, who had limited research experience but used guided inquiry extensively in her classroom. For example, she had students design investigations of what caused “bouncyness” in balls. She also taught an entire unit on the idea of inquiry and did various activities in hypothesis development. 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 an assay of bacterial DNA. This type of experience as a “technical assistant” in laboratories has not, in previous studies, been as closely linked with participants’ use of inquiry in the classroom. Joanne, however, 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 from that laboratory experience and the desire to help her own students experience inquiry as she had:

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 or answer my own questions in my secondary science experience, I want to give my students the opportunity.

For Joanne, this limited peripheral participation in research (the kind which had not helped other participants come to see science as a process nor had been linked with eventual uses of
<table>
<thead>
<tr>
<th>Name</th>
<th>Previous research/inquiry experience</th>
<th>Undergrad credits in sciences</th>
<th>Most frequent modes of instruction during subsequent 9-week teaching assignments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rachel</td>
<td>Ph.D. in Pharmacology. Extensive research work in graduate school.</td>
<td>200+</td>
<td>Taught 10th grade biology. Used guided inquiry twice. Also used discovery activities and lab skill experiences.</td>
</tr>
<tr>
<td>David</td>
<td>Received NSF fellowship in pharmacology. As Ph.D. student did several studies himself that were eventually published.</td>
<td>60 graduate credits in Ph.D. program</td>
<td>Taught 10th grade biology. Used discovery activities regularly. Used guided inquiry, asking students “Does saliva break down starches into sugars?”</td>
</tr>
<tr>
<td>Gina</td>
<td>Two research studies as undergrad in Indonesia on primate behavior. Developed questions, designed and carried out studies.</td>
<td>145</td>
<td>Taught AP biology. Required curriculum left little room for inquiry. Did not use inquiry. Did use several discovery activities and confirmation labs.</td>
</tr>
<tr>
<td>Assan</td>
<td>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.</td>
<td>165</td>
<td>Taught 9th grade biology. Used open and guided inquiry extensively. Example: Had students use models of humans skills to hypothesize evolutionary patterns.</td>
</tr>
<tr>
<td>Bill</td>
<td>3-quarter undergraduate research project on underwater landslides. Developed questions, designed and carried out one study.</td>
<td>127</td>
<td>Taught 8th grade earth science. Used confirmation labs regularly. Used open-ended activity once—requiring students to build a machine showing transfer of energy.</td>
</tr>
<tr>
<td>Amanda</td>
<td>As undergrad did quarter-long study of frog behavior at local zoo. Developed questions, designed and carried out studies.</td>
<td>115</td>
<td>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.</td>
</tr>
<tr>
<td>Joanne</td>
<td>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.</td>
<td>108</td>
<td>Taught 7th grade life science and 8th grade physical science. Used guided inquiry extensively. Example: What causes bouncing of different kinds of balls? Conducted unit on science inquiry. Did various activities on hypothecisforming.</td>
</tr>
<tr>
<td>Erika</td>
<td>Limited involvement in psychology research program. No other research/inquiry experiences.</td>
<td>83</td>
<td>Taught 10th grade biology. Used guided inquiry once in osmosis experiment.</td>
</tr>
<tr>
<td>Michael</td>
<td>Worked as an assistant in immunology lab. Did not conduct research independently. Developed “techniques” usable in industrial settings.</td>
<td>110</td>
<td>Taught 9th grade physical science. Used guided inquiry once.</td>
</tr>
<tr>
<td>Shellie</td>
<td>Did undergrad biology research with four other students examining eutal pollution. Did not collect data firsthand.</td>
<td>131</td>
<td>Taught 10th grade biology and 9th grade general science. Used some discovery activities. Students in general science class asked to assemble toy that demonstrated physics principles.</td>
</tr>
<tr>
<td>Bria</td>
<td>Brief experience at archeological dig. No other research experiences.</td>
<td>109</td>
<td>Taught 9th grade physical science. Did several discovery activities. Example: How density of water changes due to temperature changes. No forms of inquiry used.</td>
</tr>
<tr>
<td>Carmen</td>
<td>Recalled no K-16 experiences at all with guided or independent inquiry.</td>
<td>70</td>
<td>Used guided inquiry once. Also used one discovery laboratory and a confirmation activity.</td>
</tr>
<tr>
<td>Jenelle</td>
<td>Limited work with chemistry professor in molecular modeling on computer.</td>
<td>100</td>
<td>Taught 11th grade chemistry. Confirmation labs intended to lead to an understanding of chemical formulas.</td>
</tr>
<tr>
<td>Nick</td>
<td>Was a lab technician in pediatrics department.</td>
<td>84</td>
<td>Taught 10th grade biology. Used lecture and worksheets almost exclusively. No inquiry used in any form.</td>
</tr>
</tbody>
</table>

**Figure 2.** Previous research experiences, credits in undergraduate science, and use of inquiry during student teaching.
classroom inquiry) had transformed her thinking about science and what it could mean to young learners.

Discussion

... folk models, as culturally constructed common sense, are not cognitive organizations but a set of operating strategies for using cultural knowledge in the world. They comprise sets of shortcuts, idealizations, and simplifying paradigms that work well together but do not have to all fit together without contradiction into global systems of coherent knowledge (Keesing, 1987, p. 379).

If we assume that participants’ written and oral accounts reflected their thinking about inquiry, and that their thinking was substantially influenced by images of “doing science” reinforced over a lifetime of schooling and exposure to other public discourses related to science, then we may be able to identify key aspects of a shared folk theory of “doing science” (however tacit or fragmented). Participants took inquiry to be more than posing and finding the answer to a question; their knowledge-seeking activities were guided by implicit rules and operating strategies, defined by their conceptualization of inquiry.

This putative folk theory, though influenced by the idea of the Scientific Method, is not synonymous with it. Some facets of this folk theory are congruent with authentic science inquiry (e.g., empirical inquiries involve developing questions, designing studies, and collecting and analyzing data; setbacks are to be expected; etc.). Others seemed to represent a limited view of scientific inquiry (e.g., there is a scientific method, although it is not linear; the ultimate goal of inquiry is to determine whether a relationship exists between two variables; etc.). More problematically, several facets were misrepresentations of some of the most fundamental aspects of scientific inquiry (e.g., hypotheses function as guesses about outcomes, but are 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; empirically testing relationships and drawing conclusions about these relationships are epistemological “ends-in-themselves”; and models or theories are optional tools you might use at the end of a study to help explain results). Almost entirely absent from participants’ journals and interviews were references to the epistemological bases of inquiry—talk of arguments tying data to claims, alternative explanations, the development of theories of natural phenomena, and so on. Most participants, for example, based their inquiry questions not on the prospect of testing aspects of a hypothesized model but on what seemed interesting, doable, and novel (e.g., bubbling car exhaust through water to see how acidic it gets).

The types of thinking reflected by these findings can be further understood using an analytic framework developed by Driver et al. (1996). From their study of 180 middle- and high-school-aged students, they constructed a method for characterizing features of students’ epistemological reasoning about inquiry in science. They referred to the least sophisticated level in their framework as *phenomenon-based reasoning*, in which students characterized empirical investigation as an unproblematic process of finding out “what happens” or simply making phenomena happen so that subsequent behavior can be observed (e.g., growing plants in the dark, using chromatography to separate components of ink). No preservice teachers in the current study demonstrated this type of reasoning.

The next level, which most older students in Driver et al.’s (1996) study subscribed to, was *relation-based reasoning*. This is characterized by a focus on correlating variables or finding a
linear causal sequence. This typically requires an intervention to seek cause or predict an outcome. The nature of explanation refers to relations between features of a phenomenon which are observable/taken for granted. Alternative variables may be entertained; however, only one relationship is assumed to be true. This form of reasoning was predominant in the preservice teachers’ inquiries. Although it is important to be able to set up controlled interventions, identify influential variables, and understand how outcomes are related to experimental conditions, these activities are not ends in themselves. Inquiries framed by relation-based reasoning reinforce reduced forms of argumentation because the ultimate goal of such inquiries is to support a claim for a relationship between observable variables. The resulting arguments, then, focus only on the definitions of variables and the quality and accuracy of the data (methodological soundness) as well as analysis and data representation. Such a rhetorical strategy is linked to a naïve-realist approach to science—essentially, the belief that theory “emerges” from data, thus providing a faithful account of nature.

None of the participants provided clear evidence that they employed the most authentic approach to scientific thinking—model-based reasoning. This form of reasoning takes inquiry to be an empirical investigation to test or to develop a model or theory, or to compare theories. The nature of explanation that follows is that models and theories are conjectural, that explanation involves coherent stories that posit theoretical entities, that explanation involves discontinuity between observation and theoretical entities, and that multiple possible models may be entertained. Using model-based reasoning, argument can include not only querying data and methods of analysis but, more importantly, rhetorical commentary on aspects of the model that underlie the study such as assumptions made about the model, challenges to the coherence of the model, and appeals to alternative explanations.

For the 3 participants whose cases were described at length, the 2 people without research experience used no apparent models to initiate their study. Interestingly, 1 of these 2 participants “built theory” for herself out of curiosity at the end of her study by accessing relevant information from the Internet. The other of the inexperienced participants mentioned a possible explanation for her results in one brief passage, but that idea was never revisited. One participant with experience in research did provide evidence that she used an implicit theory to work with, but the language of theories and models was not present in her journaling or in her interview. There was little mention of alternative explanations for any of the participants’ findings and few connections between participants’ findings and application to natural phenomena.

The notion of a “scientific method” as an atheoretical approach to inquiry was not only exemplified through their own inquiry experiences but, in at least one case, reinforced by what they observed in schools. In this situation, experiments done by students in a sixth-grade classroom were not based on any particular scientific model but rather were comparisons between groups of plants assigned to arbitrary conditions. The model of inquiry shared among participants was more authentic than the traditional linear scientific method (Figure 3). Participants employed a model closer to that shown in Figure 4. This model reflects more of the recursive nature of inquiry (e.g., how conclusions inform new questions), the conceptual interconnectedness of the phases of inquiry (how one phase informs another), and the frequent need to rethink the inquiry activities based on what one learns at any point in the process. Participants fell short of the model depicted in Figure 5. This model subsumes the phase interconnection features of Figure 4, but also includes the ideas that (a) questions should flow from observations framed by a theoretical model (however simple) that attempts to describe or explain some natural phenomena, (b) predictive hypotheses are based on the potential validity of the model, (c) data analysis forms the basis of argument for aspects of the model, and (d) the findings are considered within the context of how well they support this tentative model.
Once a question was formulated, the participants’ thinking was focused on connections between the different stages of the study and what the final results would “show.” The procedure was important for its own sake—to test hypotheses about the relationship between observable variables—but it was not conceived as an epistemological tool to describe, explain, or predict unseen entities. These findings are consistent with an analysis of typical school-inquiry experiences by Chinn and Malhotra (2002), who reported:

... the goal of simple inquiry tasks is only to uncover easily observable regularities (e.g., plants grow faster in the light than in the dark), or the salient structures of objects, not to generate theories about underlying mechanisms. In short, the ultimate goal of most authoritative research is the development and revision of theoretical models. The goal of most simple inquiry is a Baconian gathering of facts about the world. (p. 187)

The folk theory of inquiry described in this study is characterized by oversimplifications. However, conceptualizing inquiry as a kind of technical procedure premised on relation-based reasoning may seem sensible—indeed, the text of participants’ journals may be considered by many practicing teachers perfectly acceptable accounts of “doing science.” The idea of a self-contained procedure (disconnected from theories or scientific models) with orderly steps and much of the epistemological complexity stripped away is, unfortunately, a useful fiction. Directing students in lockstep through a series of well-defined activities may satisfy the narrow intellectual aims for what passes as inquiry in many classrooms, and this highly prescribed investigative style may be the only form of inquiry seen as manageable in overcrowded classrooms. This version of scientific method, then, is a rigid procedural text—but not a way of thinking. One can complete the technical aspects of many types of classroom inquiries without reasoning beyond the procedures.
In addition to the epistemological shortcomings of the scientific method as described earlier, the failure to frame investigations using hypothetical models undermines inquiry’s connection with science content. Many school laboratory activities have little connection with scientific models, but rather are cookbook exercises; the kind of folk theory described in this article both reflects and perpetuates the artificial separation of inquiry and content in school science. More authentic forms of inquiry open up opportunities to teach with models and about the nature of models. Most teachers use facts and concepts as their objects of instruction. These are more meaningful, however, when taught within the contexts of models. Models emphasize causal, functional, temporal, spatial, developmental, and conceptual interrelationships that give meaning to otherwise noncontextualized facts and concepts. The theoretical character of some models also is an entry into discussion of the social construction of science ideas and the tentative nature of scientific knowledge.

In light of these findings, the next step in developing interventions with preservice teachers around inquiry must involve the use of models and model-based reasoning. A follow-up study is already under way in which participants are required to (a) do background reading on the focal phenomenon, (b) express their beginning knowledge of the phenomenon as a theoretical model, (c) develop questions based on hypothesized relationships from this model, (d) engage in argument around the relationships between evidence and their eventual claims, and (e) revise their original model based on their conclusions.

Connected with the participants’ vision of inquiry were descriptions of how, as teachers, they would support students’ classroom investigations. Participants identified three general strategies for instructional support. (Most participants mentioned at least two of these three general strategies.)
direct instruction on different aspects of inquiry (but interestingly, not on background content or the use of guiding theory)

- adding more structure to the inquiry process (e.g., giving students a highly restricted number of topics to choose from in designing their inquiry, fashioning research questions for students, requiring student proposals and approval by the teacher)

- using scaffolding techniques centered on sense-making activities by students and 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 students to engage in—it may have reinforced their desire for a highly structured version of the scientific method for use in the classroom. Using such a simplified sequence of events for their classrooms seemed appealing to several participants, who also acknowledged the complexity of authentic investigations. For the beginning teacher, it may seem daunting to face 24 students, each pursuing different inquiry projects, using unique approaches to collecting data, and constructing for themselves novel ways of connecting their hypotheses, data, and conclusions.

Finally, experiences with the inquiry project were not enough to compel all of these preservice teachers to attempt inquiry in their classrooms during student teaching. Only 8 of the 14 participants used some form of guided or independent inquiry in their own classrooms. As was true in the first two studies in this series (Windschitl, 2001, 2002), 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 towards a larger research objective. This suggests that
a key factor in research/inquiry experiences for preservice (or in-service) teachers is not just immersing them as legitimate participants in authentic investigative experiences but also helping them conceptualize science as a way of knowing the world rather than as a canon of content.

Conclusions

Participants in this study all held degrees in science and were part of a highly regarded master’s program in secondary science teaching. Yet, most of them subscribed to a model of inquiry that was mainly a technical procedure (albeit complex) rather than a theoretically grounded exploration. From a constructivist perspective, we know that preservice experiences can be best designed only if we first understand the frameworks of knowledge that preservice teachers bring with them to the program and the broader culturally reinforced models that maintain everyday ways of thinking about the disciplinary activities of scientists.

One recommendation for methods instructors in teacher education programs is to use such inquiry experiences. (Participants in this study did report advancing their understandings of the procedures involved in experimentation, in their appreciation of the complexity of the process, and in ideas about how to scaffold learners.) but require that inquiries be based on theoretical models. In this exercise, preservice teachers should immerse themselves in background reading on the subject of their inquiries, be able to represent the salient models they will use as a basis for their investigations, and frame their questions in terms of that model. They should learn how to argue claims in science and engage in such arguments based on their own inquiry. Whole-class discussions should make explicit the tenets of model-based inquiry that remain invisible in the protocol of the traditional scientific method. And it would, of course, be a more powerful experience if the beginning teacher could then be placed under the mentorship of a cooperating teacher in whose classroom model-based inquiry is practiced. For those programs that cannot provide such an inquiry experience, an alternative would be the development of content courses taught within the context of inquiry and designed especially for teachers. Such courses in biology, chemistry, earth sciences, and physics would feature a few key ideas in each domain that would be represented as models and that emphasize the development of these models through a combination of background reading, theorizing, empirical investigations, and argument. In this study, conventional college-level science courses had little apparent influence on participants’ understanding of the nature of science and did not prepare them to engage in the discourse of authentic science. Another alternative would be to assign preservice teachers to work in laboratories or in the field with scientists for an extended period of time. This option, however, is less than ideal given that such partnerships rarely allow the teacher to participate in meaningful ways in investigations, and scientists are not well versed in how to make their thinking explicit to others, compromising the nature of the “apprenticeship.” Regardless of the strategy for helping teachers understand the processes of science, it is clear that professional development in this area must continue throughout the career of the teacher. Familiarity with the methods of inquiry, domain-specific reasoning, and knowledge of relevant content in a domain takes years of study.

In summary, the science education community cannot discount the power of folk theories to influence inquiry-oriented instruction. These folk theories, though mostly tacit, may have more influence on practice within the science education community than authoritative documents offering guiding principles for doing science, widely disseminated prototypical examples of authentic forms of inquiry, or curriculum. D’Andrade (1987) suggested that models such as the Scientific Method persist because their formulaic and linguistically economic construction signals a kind of cultural wisdom handed down from authoritative figures to practitioners—in this case, from scientists to educators. Teachers, then, as carriers of these discourses, are subject to and
eventually reinforce folk theory about how science is done. As thousands of new science teachers enter classrooms each year, they too will be influenced by and in turn contribute to the folk theory of inquiry detailed in this study.

Notes

1 Folk theories share important features with schemas or scripts. These are representations that, like folk theories, play a dynamic role in guiding expectations and actions and are a shared possession by bearers of a culture. However, there are key differences between schemas and folk theories. First, folk theories are not tied to physical settings, which serve as cues for expectations and behavior (e.g., as in a restaurant or on a beach). Second, the idea of schemas and scripts have not been attributed to culture but to some pan-human experience. Scripts assume (without cultural background) that individuals’ understandings of the world are accumulated through generalization of knowledge from one firsthand experience to another. Finally, folk theories not only include knowledge structures of individuals but also reside in social practices, institutional regularities, media messages, and cultural artifacts.

2 Around the middle of the 20th century, the Scientific Method was offered as a template for teachers to emulate for the activity of scientists (National Society for the Study of Education, 1947). It was composed of anywhere from five to seven steps (e.g., making observations, defining the problem, constructing hypotheses, experimenting, compiling results, drawing conclusions). Despite criticism beginning as early as the 1960s, this oversimplified view of science has proven disconcertingly durable and continues to be used in classroom today (DeBoer, 1991), thus dismissing the complex, creative, and imaginative nature of the scientific endeavor (Abd-El-Khalick & BouJaoude, 1997; Lederman, 1992).

3 Models and theories belong to the family of scientific representations. Scientific models are purported relationships among objects, events, and processes in the natural world that help describe, explain, or predict phenomena. The relationship between models and theories is a contested issue. Theories can be thought of as models that explain governing principles of some phenomena (as opposed to those models which only describe relationships). See Wartofsky (1966) for a thorough critique of these distinctions.

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

2) If some form of inquiry used, circle one variation in each of the 5 rows that best describes the student teacher’s approach for each of the five “essential features.” Not all 5 of the “essential features” will be observable in a given class session, even if they are using inquiry.
<table>
<thead>
<tr>
<th>Essential Feature</th>
<th>Variations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Learner engages in scientific-oriented questions.</td>
<td>Learner poses a question.</td>
</tr>
<tr>
<td>2. Learner gives priority to evidence in responding to questions.</td>
<td>Learner determines what constitutes evidence and collects it.</td>
</tr>
<tr>
<td>3. Learner formulates explanations from evidence.</td>
<td>Learner formulates explanation after summarizing evidence.</td>
</tr>
<tr>
<td>4. Learner connects explanations to scientific knowledge.</td>
<td>Learner independently examines other resources and forms the links to explanations.</td>
</tr>
<tr>
<td>5. Learner communicates and justifies explanations.</td>
<td>Learner forms reasonable and logical argument to communicate explanation.</td>
</tr>
</tbody>
</table>

References


