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Just Do It? Impact of a Science Apprenticeship Program on High School Students' Understandings of the Nature of Science and Scientific Inquiry

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Abstract: The purpose of this study was to explicate the impact of an 8-week science apprenticeship program on a group of high-ability secondary students' understandings of the nature of science and scientific inquiry. Ten volunteers (Grades 10–11) completed a modified version of the *Views of Nature of Science, Form B* both before and after their apprenticeship to assess their conceptions of key aspects of the nature of science and scientific inquiry. Semistructured exit interviews provided an opportunity for students to describe the nature of their apprenticeship experiences and elaborate on their written questionnaire responses. Semistructured exit interviews were also conducted with the scientists who served as mentors for each of the science apprentices. For the most part, students held conceptions about the nature of science and scientific inquiry that were inconsistent with those described in current reforms. Participating science mentors held strong convictions that their apprentices had learned much about the scientific enterprise in the course of doing the science in their apprenticeship. Although most students did appear to gain knowledge about the processes of scientific inquiry, their conceptions about key aspects of the nature of science remained virtually unchanged. Epistemic demand and reflection appeared to be crucial components in the single case where a participant experienced substantial gains in her understandings of the nature of science and inquiry. © 2003 Wiley Periodicals, Inc. J Res Sci Teach 40: 487–509, 2003

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Recent reforms in science education stress the importance of precollege students' developing current understandings of the nature of science and scientific inquiry [e.g., American Association for the Advancement of Science (AAAS), 1989; National Research Council (NRC), 1996]. The rationale behind this goal is the development of scientific literacy for all citizens. Scientific literacy is commonly portrayed as the ability to make informed decisions on science and technology–based issues and is linked to deep understandings of scientific concepts, the processes of scientific inquiry, and the nature of science. Unfortunately, research has consistently shown that students typically do not develop such understandings through their participation in school science (Aikenhead, 1973; Bady, 1979; Broadhurst, 1970; Duschl, 1988; Larochelle & Desautels, 1991; Lederman, 1992; Lederman & O'Malley, 1990; Matthews, 1994; Meichtry, 1992; Rubba, Horner, & Smith, 1981; Welch, 1979, 1981).

A common recommendation among these and other studies has been for educators to provide students with opportunities to do science through either in-class science projects or extracurricular work with scientists. Indeed, both scientists (NRC, 1996; Rock & Lauten, 1996) and educators (Gallagher, 1991; Lemke, 1990; Schmidt, 1967; Solomon, 1991; Tobin & Gallagher, 1987) have supported programs and curricular materials that involve students in authentic science research. Science educators have assumed that working on authentic science research projects facilitates the development of scientific literacy by enhancing students' understandings of science content, the processes and logic of scientific inquiry, and the nature of science. For example, the *National Science Education Standards* stress the efficacy of learning of science content within the context of real-world problems and phenomena (NRC, 1996). By experiencing the messiness of doing science, science educators have hoped that students would go beyond learning science content to experiencing and learning about the processes of science. Furthermore, opportunities to experience science-in-the-making and engaging in discourse with professional scientists could possibly lead to better understandings of the nature of science.

Involvement in scientific inquiry can range from relatively brief classroom activities to lengthy projects in research laboratories. It is generally believed that the more authentic the research experience, such as an apprenticeship guided by a science professional, the more likely students will learn about aspects of scientific inquiry (Barab & Hay, 2001; Ritchie & Rigano, 1996). In regard to learning the processes of science, Hodson (1993) explained,

> Because the ways in which scientists work are not fixed and not predictable, and because they involve a component that is experience-dependent in a very personal sense, they are not directly teachable. That is, one cannot learn to do science by learning a prescription or set of processes to be applied in all situations. The only effective way to learn to do science is by *doing* science, alongside a skilled and experienced practitioner who can provide on-the-job support, criticism, and advice. (p. 120)

In answer to this and similar calls, a variety of programs have sought to place students in research laboratories or special programs to develop broader and more complete understandings of the processes and nature of science (Barab & Hay, 2001; Bleicher, 1996; Cooley & Bassett, 1961; Krasny, 1999; Richmond & Kurth, 1999; Ritchie & Rigano, 1996).

In addition to learning the processes of doing science, researchers and program developers have hoped that students would learn about the scientific enterprise through participation in authentic science experiences (Krajcik et al., 1998; Means, 1998; Moss, Abrams, & Kull, 1998; Moss, Abrams, & Robb, 2001; Ruopp, 1994; Ryder & Leach, 1999). In other words, students are expected to make gains in their understandings of the nature of science and scientific inquiry. This learning is sometimes seen as a natural outcome of students' participation in scientific inquiry. For example, Moss et al. (2001) expected high school students to learn about the nature of science through collaboration with scientists on research projects. Speaking about their own expectations for the project, Moss and colleagues explained:

> The inclination to think that the nature of science can be taught implicitly was clearly evident in this study. It was assumed that if students were actively engaged in doing science in this project-based class, they would as a by-product of those experiences develop a deep understanding of the nature of science. (Moss et al., 2001, p. 788)

Other researchers such as Ryder, Leach, and Driver (1999) have described the process through which this learning may occur as developing through discourse among students and science professionals in which scientific perspectives and the nature of science are discussed routinely and spontaneously.

Clearly, science apprenticeships provide the potential for students to receive both implicit and explicit messages about the nature of science and scientific inquiry. In fact, some researchers have suggested that desired understandings may best be achieved through a combination of implicit and explicit messages, with the expert–apprentice relationship serving as an effective source of these messages (Ryder & Leach, 1999). However, the quality and degree to which explicit messages are generated in expert–apprentice relationships have not been fully characterized in the literature. Furthermore, there are conflicting results regarding students' gains in understanding as a result of implicit messages during investigative work with scientists (e.g., Moss et al., 2001; Ryder & Leach, 1999; Solomon, 1991). As Moss et al. (2001) aptly stated, "Understanding the relationship between explicit instruction and implicit messages of the nature of science is critical if we are to effectively teach the nature of science" (p. 789).

The purpose of this study was to explicate the impact of an 8-week science apprenticeship program on a group of high-ability secondary students' understandings of the nature of science and scientific inquiry. Two principal goals guided the investigation: (a) to characterize changes (if any) in participating students' understandings of the nature of science and scientific inquiry, and (b) to assess the effects (if any) of the implicit and explicit messages generated during the apprenticeship experience on participating students' understandings of the nature of science and scientific inquiry.

The Apprenticeship

The apprenticeship program that served as a treatment in this investigation has a 10-year history of placing students in science laboratories throughout a Pacific Northwest state. Apprentices worked in laboratories for an 8-week period during the summer, usually between their junior and senior years in high school. Interested students underwent a rigorous application process requiring demonstrated academic success, an extensive written application, and subsequent interviews with the research mentors. Participation required active involvement in a research project and presenting research results at a conference at the conclusion of the apprenticeship. Typically, the apprenticeships began with the apprentices reading literature pertaining to the research conducted in their laboratories. The mentors, who were university science or engineering research faculty, introduced the apprentices to other members of the research team and the current research projects. The apprentices then participated in aspects of the ongoing projects, or conducted a spin-off research project of interest. The mentors and the laboratory workers provided guidance throughout the duration of the apprenticeship. Each apprenticeship culminated in an oral presentation as part of a university symposium.

One of the primary goals of the apprenticeship program was to provide high school students with authentic science research experience that would assist them in making choices about science careers. Therefore, mentors were encouraged to engage the apprentices in all aspects of research, and not merely the grunt work often assigned to temporary laboratory employees. To ensure compliance with this objective, mentors and apprentices attended orientation meetings that outlined program goals and procedures. In addition, program staff visited students and mentors at various intervals throughout the program to monitor apprenticeship projects and student progress.

Several of the components of science inquiry skills outlined in the *National Science Education Standards* (NRC, 1996) were components of the apprenticeships, particularly dealing with collecting data, constructing and testing explanations, and communicating results. A few students were given the freedom to investigate their own research questions. Research within the apprenticeships generally covered a breadth of life and physical science topics, and most required apprentices to learn a significant number of procedures and skills. Sample apprenticeship descriptions are provided in Appendix A.

Method

Ten volunteers (6 females, 4 males) were purposely selected from the 18 high school students (Grades 10–11) participating in a science and engineering apprenticeship at a Northwest university. Selection was based upon the apprentices' participation in apprenticeship projects previously identified as providing opportunities for high levels of inquiry (Bell & Blair, 1997) as opposed to apprenticeships focused on conducting specific tasks such as writing computer programs. Each high school apprentice worked within a laboratory full time for 8 weeks during the summer, with opportunities to participate in research design, data collection, and data analysis.

Before the first week of their apprenticeship, the apprentices were given a modified version of the *Views of Nature of Science, Form B* (VNOS-B) to assess their conceptions of the nature of science and scientific inquiry (Appendix B). The questionnaire included six open-ended questions from the VNOS-B (Lederman, Abd-El-Khalick, Bell, Schwartz, & Akerson, 2001) plus two additional questions designed to assess apprentices' knowledge of scientific inquiry and abilities to do scientific inquiry. The same questionnaire was administered as a posttest at the end of the 8-week apprenticeship to determine whether the students' conceptions of science changed during their apprenticeship experiences.

Currently, there is much debate among science educators regarding a specific definition of the nature of science. Such disagreement is to be expected given the multifaceted nature of the scientific enterprise, and given that our understandings of the nature of the scientific enterprise have evolved over time (Lederman, 1992). Despite the lack of consensus on a specific definition, there is considerable agreement at a certain level of generality among those who study the workings of science and its nature, particularly when appropriateness for K–12 instruction is considered (Lederman et al., 2001; Smith et al., 1997; Smith & Scharmann, 1999). The VNOS-B was designed to assess understandings at this level of generality, and included open-ended questions intended to elicit students' understandings about the nature of scientific knowledge and the scientific enterprise. For an in-depth description of the VNOS-B and its validity, see Lederman et al. (2001).

The last two questions of the instrument were designed to assess students' understandings of scientific inquiry, as reflected in current science education reform documents (AAAS, 1989, 1993; NRC, 1996). The questions, in conjunction with the follow-up interviews, were designed to provide opportunities for respondents to apply their understandings of aspects of doing inquiry (formulating questions, designing investigations, dealing with data, constructing explanations, testing explanations against current scientific knowledge, and communicating results) as well as their knowledge about inquiry (scientists use varied methods, test ideas, and use current knowledge). Content and face validity of the modified 8-item version of the VNOS-B was provided through modifications suggested by a panel of three science educators.

The semistructured exit interview protocol (Appendix C) provided the apprentices with an opportunity to describe the nature of their apprenticeship experiences and elaborate on their written responses to the VNOS-B. The interviews allowed the researchers to probe students' conceptions of the nature of science and scientific inquiry and provided a means of triangulating their responses to the pre- and postquestionnaires. In addition, the interviews provided the researchers with the opportunity to explore the role of the research experiences in shaping the apprentices' conceptions of science.

In addition to the modified VNOS-B and interview responses, the researchers compiled notes from visits to the laboratories and field sites where the apprenticeships were conducted. These data included observation summaries of the apprenticeship experiences and notes from informal discussions with apprentices, supervisors, and scientist mentors. At the conclusion of the 8-week program, the apprentices presented their work in a poster session. The researchers attended these presentations and took notes to summarize the apprentices' descriptions of their work and record the informal discussions that ensued.

Semistructured exit interviews were also conducted with the scientists who served as mentors for each of the science apprentices (Appendix D). The mentors were interviewed at the conclusion of the program to provide additional information about the apprenticeships and the degree of explicit instruction they had provided related to the nature of science and scientific inquiry. The mentors were also invited to discuss any additional aspects of the apprenticeships that they viewed as significant factors affecting student learning.

The researchers pursued follow-up questions during both apprentice and mentor interviews to obtain more detailed responses. The interviews were audiotaped and transcribed. All four researchers analyzed the questionnaire responses and interview transcripts. Before analyzing the entire data set, three identical, randomly selected samples of each of the data sources were independently analyzed by each of the researchers. Results of these three analyses were subsequently compared to establish interrater agreement on the categorization of the apprentices' understandings of the nature of science and scientific inquiry. Better than 95% agreement among the three researchers was achieved.

The analysis focused on generating in-depth profiles of the participants' understandings of the nature of science and scientific inquiry before and after their apprenticeship experiences. In this analysis, the various data were first analyzed individually using Bogdan and Biklen's (1992) model of analytical induction and then together to test the validity of developing assertions. In this approach, working hypotheses to describe and explain the participants' views were continually formed and then tested against subsequent data. The ultimate goal was to develop generalized assertions for the apprenticeship experience derived from systematic examination and re-examination of the available data. The variety of data sources (apprentice questionnaire and interview responses, mentor interview responses, notes from site visits, and notes from the poster session presentations) permitted the triangulation of data and supported the validity of the profiles of each apprentice's understandings and apprenticeship experience. Questionnaire and interview data were analyzed in this manner to generate pre- and postapprenticeship profiles of the participants' understandings of the previously discussed aspects of the nature of science and scientific inquiry. Next, the researchers compared each participant's pre- and postapprenticeship profiles to determine the degree of change that occurred during the apprenticeship. The site visit and poster session notes were examined to construct detailed descriptions of each apprenticeship experience. Finally, the mentor scientist interview responses were examined to characterize the type and level of instruction that each apprentice received regarding the targeted aspects of the nature of science and scientific inquiry.

Results

The results are presented in three sections. The first section focuses on understandings of the nature of science and the second section focuses on understandings of scientific inquiry. In each of these sections, changes in the apprentices' views during the apprenticeship program and the origins of their views are elucidated. The third section describes the mentors' views of their role in the development of the apprentices' understandings.

For clarity of presentation, codes are used to identify individual participants' responses to the various data collection instruments. Each code consists of a letter–number combination, with the letter distinguishing apprentices ("A") and mentors ("M") and numbers indicating specific apprenticeships (1–10). Data sources are identified as pre-VNOS-B (preapprenticeship application of the modified VNOS-B questionnaire), post-VNOS-B (postapprenticeship application of the modified VNOS-B questionnaire), or EI (Exit Interview). Thus, "A7, pre-VNOS-B" refers to a preapprenticeship response to the VNOS-B by the apprentice working on project No. 7. "M7, EI" refers to the exit interview response of the scientist mentoring that same project.

Conceptions of the Nature of Science

Analysis of the preapprenticeship VNOS-B responses revealed that participants' understandings of assessed aspects of the nature of science for the most part were inconsistent with those identified in current reform documents. Furthermore, analysis of the postapprenticeship VNOS-B and exit interview data revealed few changes in the apprentices' understandings of the nature of science over the course of the 8-week apprenticeship program. The apprentices' understandings of the nature of science (and any changes in their understandings) are highlighted in the following summary descriptions, with representative excerpts from their written and verbal responses.

Initial Conceptions of the Nature of Science. Before beginning their individual apprenticeships, the participants' understandings resembled those reported in previous investigations in that they were largely incomplete, or otherwise inconsistent with contemporary interpretations of the nature of science. For example, whereas all of the participants expressed awareness of the empirical nature of scientific claims, they tended to see data as the sole determinant of change in scientific ideas. As such, all of the apprentices expressed the view that theories can change as new evidence is brought to light. However, as a whole, the group did not appear to understand that theories might also change owing to new perspectives for looking at existing data. Overemphasis of the empirical nature of scientific knowledge extended into the participants' views of laws, where the participants often confused scientific laws with facts and cited the common misconception that laws represent absolute knowledge.

> Laws, as I understand them, would only change if something in our nature, like our environment, changed. As far as I know, laws don't change because they're facts. (A2, pre-VNOS-B)

> A scientific law is definite, and nothing is named a law unless scientists agree that there is no question to its being true. For example, scientists are open to finding new information

> about the atomic theory, but Newton's law of motion has been tested enough times that scientists are certain it is true. (A3, post-VNOS-B)

Closely linked to their absolute view of scientific laws, the apprentices also expressed the misconception that theories and laws are the same kind of knowledge, separated only by the degree of certainty ascribed to them.

> Okay, I think I decided that a scientific law would represent something that had been a theory. It had been proven so many times and under so many circumstances and conditions that it had elevated into a law, something that, I guess, has withstood the test of history. And a scientific theory would be something that had been more recently proposed and may hold up, still, to our tests, but has not been around long enough to be proven as a law. (A5, EI)

All of the participants ascribed some role for creativity in the initial stages of scientific investigations. However, their responses indicated a failure to recognize creativity as inherent and necessary throughout all stages of investigations.

> A10: I think that scientists should not use their imagination in some circumstances. In interpreting the data, they should go strictly with what's in the data. If they sort of try to make it slant one way or the other, or you get two people doing the same experiments, and they have the same data and they get different conclusions, I think that that is because they sort of have creative answers to what their data is showing.
>
> Researcher: Is that okay?
>
> A10: No—if you have data, you should go with what the data says.

On the surface, the apprentices appeared to dismiss the view of science as completely rational and objective. However, when their conceptions were probed more deeply during the exit interviews, all but two expressed viewpoints leaning toward a more absolute view of science as an objective endeavor. For example, some described the different conclusions reached by astronomers in Item 6 of the VNOS-B as the result of looking at different data (despite the item's wording to the contrary). Others reconciled the different interpretations with their objective views by referring to incomplete or inaccurate data. Still others suggested that some of the scientists were misinformed or even dishonest.

> I think people can distort data in many ways.... Depending on what the scientists want to believe, they can strategically choose only certain time periods to reflect their data (distorting the facts) instead of looking at the whole picture. (A8, EI)

Overall, the apprentice responses painted a picture of subjectivity in science as inevitable but something to be avoided. None linked subjectivity in science to creativity, nor did they express understandings of the theory-laden nature of data interpretation. Finally, the effects of social and cultural contexts in which scientific investigations are embedded were almost entirely overlooked by the apprentices in this study. All 10 of the apprentices in this investigation focused on personal bias or beliefs when discussing the different interpretations the astronomers reached in Item 6. In all of these expressed views, the apprentices' understandings were consistent with the large body of research finding that secondary students' understandings seldom match targeted aspects of the nature of science (e.g., Aikenhead, 1973; Lederman, 1992; Meichtry, 1992).

Changes in Views of the Nature of Science. Postapprenticeship questionnaire and interview responses indicated little change in participants' understandings of the nature of science. In fact, despite participation in an authentic, inquiry-oriented science apprenticeship program, none of the 10 participants were found to have adequate understandings of the nature of science. When the participants were asked about the sources of their understandings (whether adequate or not), references to their apprenticeships were conspicuously absent even though apprentices were aware that they were recruited to the study based on apprenticeship participation. Instead, the apprentices referred to their science classes, personal reading, and parents as the primary sources of their understandings. The following response is both typical and notable, especially when compared with the mentors' beliefs regarding how the nature of science should be taught (as described in a subsequent section):

> Working in the [apprenticeship] program changed my views of the specific field I was working in, because before I thought, it's just wood, you know? What can you do with it? Now I know a lot more about that specific field, but things such as these [nature of science questions], it didn't do a lot to change my opinion of them . . . Nobody ever really discussed any of these topics with me. (A8, EI)

The only student who experienced substantial changes in her understandings of the nature of science that can be attributed directly to the apprenticeship experience was Apprentice A2. For example, before her apprenticeship, A2 viewed the progression of theories as linear, with one largely accepted theory dominating a particular scientific field at any point in time. However, after her experience conducting field studies with reptiles and amphibians, she experienced a major change in her views.

> Researcher: So, did your views of theories change over the course of your apprenticeship?
>
> A2: Yes, I think so. I just realized through my apprenticeship how often multiple theories are in existence at the same time. . . . I think at any one time in any field there are multiple theories, multiple ways of explaining why things occur. If one group of people interpret current knowledge to mean one thing, and another group interpreted the same knowledge to mean something else, then they could develop very different theories. No new knowledge is necessary. (A2, EI)
>
> Researcher: That's a pretty interesting idea—where did you learn that?
>
> A2: My apprenticeship itself—that definitely contributed to the answer I just gave, because you see it in real life. I went out once to do some fieldwork with some guy who was an influential scientist in the herpetology world. He did a lot of work regarding the mutated frogs. While I was out with him looking at these mutated frogs, he was talking about the different theories of what was causing the mutations. Some thought it could be an increased concentration of pollutants; others were still holding on to the UV ray theory. He was just trying to explore both of those ideas at the same time. I guess that was one time when I saw new theories and old without any groundbreaking experiments.

Clearly, this apprentice's understanding of scientific theories was enhanced by her apprenticeship experience. Working on a line of research in which competing theories were the norm forced the apprentice to confront some of her preconceived notions of scientific theories. Ryder and Leach (1999) referred to this forced dissonance as epistemic demand: that is, the demands that a project makes on a student to draw on his or her views about the relationship between data and knowledge to make progress on the project. The effect of this epistemic demand was likely enhanced by the particularly reflective nature of the apprentice—a characteristic evident in the thoughtfulness of her responses and in the fact she mentioned that her friends at school often refer to her as the Thinker.

Apprentice A2's experiences also led her to adopt a more accurate view of the seminal role that creativity plays throughout scientific investigations. This realization led her to abandon the view of a single scientific method and to realize that there is a clear creative component to developing scientific conclusions.

> A2: Creativity and imagination is definitely needed during data collection in overcoming unforeseen practical problems. Creativity and imagination is also extremely helpful and possibly necessary during the analysis of the data collected. In my experiment this summer, my data did not at first appear to be conclusive. Neither snake length nor mass was associated with reproduction, but when I analyzed length and mass together (mass per unit length), I found a clear conclusion that this measure of body condition was indeed associated with whether or not female red-sided garter snakes chose to reproduce.
>
> Researcher: Would you say that you discovered this conclusion, or did you create this conclusion?
>
> A2: Creativity in my mind means something, I don't know, looking at something from a different point of view. Working in new ways with your materials, or with your data. So, I guess you could say I created it, if you use that definition. (A2, EI)

The only other apprentice who experienced change in her understandings of the nature of science was Apprentice A3. In response to the second item of the preapprenticeship questionnaire, Apprentice A3, like the majority of her cohort, described the atomic model as something that can be viewed directly and appeared to confuse the model, which is based on inferential evidence, with reality. In her postapprenticeship response, A3 changed her earlier view of direct observation of the internal structure of the atom to a view based on indirect evidence. However, when asked during the interview to elaborate on the source of this apparent change, the apprentice explained,

> It wasn't something that changed because of my apprenticeship. I think I just kind of rethought it in my brain, because after I took that questionnaire I started thinking about the answers more and trying to decide if that was right. (A3, EI)

In this instance, the change in understanding came about through reflection on the VNOS-B questionnaire itself, rather than through the apprenticeship experience.

Understandings of Scientific Inquiry

Although apprentices developed increased levels of expertise in the various processes of scientific inquiry (the doing of science), few apprentices demonstrated an increased understanding about the nature of scientific inquiry (learning about inquiry). One would expect that students immersed in an intensive 8-week science apprenticeship would gain knowledge of various aspects of doing science, including how to design investigations, develop hypotheses, collect and analyze data, construct explanations, and communicate their findings. Indeed, many of the participants believed that they learned more about doing science owing to their participation. Despite the sustained involvement in an authentic science experience, however, most apprentices clung to their original and, for the most part, incomplete ideas about the nature of scientific inquiry.

Acquiring Abilities to Do Inquiry. During their respective exit interviews, both apprentices and mentors reported that the apprentices engaged in many aspects of doing science throughout the apprenticeship program. Lab safety and following prescribed procedures figured prominently among the apprentices' descriptions of their work and what they had learned.

> Probably the biggest thing I learned was how to work in a lab, lab safety, how important it is to do things the right way, and to know what you're doing when you're doing it. (A3, EI)

> What hit me most was that everything needed to be recorded in detail. I didn't really think about how meticulous scientists had to be. I definitely got a clearer idea of the scientific process over the summer. (A1, EI)

All of the apprentices spoke of learning new skills specific to the research projects to which they were employed.

> A lot of the work was with micropropagation technique. There were a few other people working in the tissue culture lab and we pretty much learned what they did . . . like transferring plants from test tubes to boxes, going out into the fields, and collecting the plants. (A4, EI)

The fact that many of the apprentices' work involved extensive data collection was clearly reflected in the descriptions of what they had learned. Whereas much of this work tended to be mundane, all of the apprenticeships afforded at least some opportunity to construct meaning from data and formulate conclusions.

> I did all the data collecting, like weighing and measuring the snakes, as well as keeping track of where they came from, keeping the snakes separated. I had a bunch of animal husbandry responsibilities. . . . We talked a lot about what makes an appropriate conclusion and what doesn't. For example, you can lie with statistics. (A2, EI)

> We tried to explain why we got the results that we did, and we both had ideas about that. (A5, EI)

In addition to data collection, apprentices were given responsibilities for day-to-day operations in the lab and helped with resolving problems that developed.

> I set up experiments, I ran the experiments. I did some research on it. I was pretty much in charge of almost everything. I would talk with the professor every once in a while about where he wanted me to go with this, and then [it] was pretty much up to me, how I got there. (A10, EI)

> I have learned more about the nature of conducting experiments and running tests than I ever would in a science class. (A7, EI)

The apprentices had rich experiences in doing science in terms of carrying out the scientist-designed experiments. One aspect of scientific inquiry absent from many of the apprenticeships, however, was the opportunity for apprentices to participate in developing research questions. The work of formulating broad questions, refining and refocusing these into research questions, and designing investigations is a critical aspect of the scientific process missing in much of high school science. One advantage of science apprenticeships is the potential opportunity for students to experience these early stages of the scientific process. However, to complete their projects during the relatively short duration of the apprenticeship program, students typically worked on projects for which this groundwork had already been laid.

> It was a small project [the effect of different treatments inhibiting fungal growth in different woods] that I totally worked on. I started on it when I got there, and finished by the time I left. I didn't design the experiment. They did it for me. (A8, EI)

However, even in the cases where the general procedures had been determined before the apprentices' arrival, there were opportunities for them to contribute to the experimental design as the investigation unfolded.

> My role in this research was to see if the different substrates would affect the performance of them. The particular bacteria that I worked with was *Pseudomonas*. It breaks down butane. I modified the experiment to test if it breaks down pentane as well. (A7, EI)

Clearly, the research projects the apprentices participated in provided many opportunities for them to experience and learn about doing science. Certainly they developed new skills specific to the projects on which they worked. The data, however, indicate that the program primarily reinforced the conceptions they already held about doing scientific inquiry. Apprentices expanded on some of the abilities related to doing science that are commonly addressed in high school curricula (safety, recording data, constructing graphs, and drawing conclusions). However, partly because of the somewhat limited duration of the apprenticeship, most did not have opportunities to expand their abilities in the direction of formulating research questions or designing their own investigations.

Developing Knowledge about Scientific Inquiry. Although the apprenticeship experience appeared to reinforce and enhance students' abilities positively to do scientific inquiry, it did little to improve their knowledge about scientific inquiry. One pervasive misconception to which apprentices held fast was their belief in the scientific method. Much has been written about the myth of a single scientific method (Bauer, 1994; Lederman, Farber, Abd-El-Khalick, & Bell, 1998; Shapin, 1996) and the misconception is explicitly addressed in the *National Science Education Standards* (NRC, 1996). There is no single prescribed set of procedures that all scientists follow when conducting investigations. Rather, scientists use a variety of methods and approaches when conducting research. What is typically taught as the scientific method can be described more accurately as experimental method, which is but one of the many methods used in science (McComas, 1996).

The 10 apprenticeship projects covered in this study included a variety of qualitative and quantitative methods ranging from descriptive to experimental. On the surface, one might expect to find that apprentices involved in nonexperimental investigations would at least begin to question their conceptions of a single scientific method. This turned out not to be so—whether participating in experimental or more qualitative research, the apprentices' views of the scientific method remained unchanged and unchallenged, with 7 of the 10 apprentices referring to a single scientific method in both their pre- and postapprenticeship questionnaires.

> The scientific method is a step-by-step process to solving a problem . . . scientific investigations should follow the scientific method. (A10, EI)

> All good scientific investigations should follow the scientific method, which is a specific process by which a hypothesis is made, then tested, and either proven correct or incorrect. If the method is not followed (even to a certain degree), then there may be holes in the argument. (A5, EI)

Some of the apprentices worked on experimental projects, in which variables were controlled and manipulated to test hypotheses. For example, Apprentice A8 investigated the effect of adding various concentrations of glucose and ammonium nitrate solutions on the growth of a particular wood stain–inhibiting fungus. Not surprisingly, these students indicated that their apprenticeship experiences reinforced their views of a single scientific method. However, even students who participated in observational studies typically adhered to the misconception of a single scientific method. For example, Apprentice A3 worked in a germ plasm repository collecting observational data on the growth and development of cloned plants. Although she participated for 8 weeks in nonexperimental scientific work, her exit interview responses reflected a commitment to the scientific method as the only way to do valid science.

> Researcher: Do all scientific investigations follow the scientific method?
>
> A3: I'm sure that there are some experiments that do not follow the scientific method, because there's some steps in there that they can't do for some reason. But that wouldn't really be considered a science, because it's not following the method completely.
>
> Researcher: Is there any other science besides science experiments? Is there anything that a scientist might do that does not follow the scientific method, but is still considered science?
>
> A3: I've never thought about that before. It seems if you think about it, if a scientist was trying to determine something, then they would always use the scientific method, because that's the way you find a conclusion. (A3, EI)

Like the majority of the respondents, Apprentice A2 connected science with the scientific method. However, she appeared on the verge of changing her views, apparently because of the observational nature of her apprenticeship experience.

> I probably still can't list all the steps, because that is not what we were doing. I think being in the middle of it, and using it, showed you what it was. I still never looked at a chart and followed any flow chart, you know, that is step one, that is step two. Like with the native snakes we were making observations on, we have absolutely no way of monitoring their environment at all. So then what we are looking at is similarities between them. (A2, EI)

Although most apprentices restricted valid science to the scientific method, three maintained that there are many ways to do science. As one apprentice put it: "Not all scientific investigations follow the exact same method. Some do not lend themselves well to experimentation . . . there is no one set scientific method" (A9). However, each of these apprentices associated this knowledge with factors other than their apprenticeship experiences, including secondary science classes, personal readings, and even discussions with their parents.

> Theoretical physicists, they don't do experiments. They derive proofs and stuff like that. Astronomers, they don't, and I guess, biologists. People that work with space a lot, the stars, they don't actually run experiments. . . . In school we actually followed the scientific method. It is good for school; it is not great for other research, because it is too strict. Research really needs to be done in a flexible environment. Most scientists don't pull out a

> sheet, and say, This is the scientific method—I have to follow that. My dad is a physicist, and that is pretty much how they do it. And I know a lot of this stuff because he talks about it a lot. (A7, EI)

Apprentice A7's comments were not unique in attributing what he knew about science to sources other than the apprenticeship experience. A common theme that emerged from the apprentices' exit interview responses was that discussions with mentors centered mainly on immediate tasks and procedures, rather than on the larger picture of what science is and how their work fit within the framework of scientific inquiry.

Another aspect of knowledge about scientific inquiry advocated in the *National Science Education Standards* is the notion that science involves testing ideas. The understanding that the scientific endeavor involves testing ideas was evident throughout the apprentices' responses to the pre- and postapprenticeship questionnaires and interviews. Many of these were in response to the last item on the questionnaire that asked respondents to design an investigation.

> If I see some differences between the occupied and unoccupied birdhouses, [I would] research that area more to see if that is really the cause of it. For instance, if I found out that the 14 birdhouses that were occupied had a close food source, I might take half of the unnested birdhouses and put some more feeders by them and see if the birds would come. (A8, EI)

> Researcher: What do you mean by "experiment" on the last question?
>
> A2: You know, like a test to see if one factor seems to be making a huge difference. I think it's a matter of finding that factor or factors. (A2, EI)

The apprentices' posttest responses were no more complete or elaborate than their preapprenticeship responses regarding their understandings of testing ideas. Thus, the apprentices apparently learned what they knew about this aspect of scientific inquiry before entering the apprenticeship program.

Finally, analysis of the questionnaire and interview responses showed that none of the apprentices indicated that it would be important to consider existing knowledge when designing their birdhouse investigations (Question 8). This is surprising given that all of the mentors required their apprentices to review existing literature before beginning their apprenticeship work. In addition, few of the apprentices mentioned that scientific research typically results in new questions. It is unclear from the existing data whether their failure to mention this reflected a belief that new questions are not a primary outcome of scientific investigation. Although two of the apprentices referred to developing new questions in their own projects, this aspect of scientific inquiry was not evident in their discussions of the investigations they developed for Item 8 of the questionnaire.

In summary, except for formulating questions, apprentices' understandings of the six aspects of doing inquiry (formulating questions, designing investigations, dealing with data, constructing explanations, testing explanations against current scientific knowledge, and communicating results) appeared to be reinforced by their work with scientists. This finding is expected. However, there appeared little if any change in their understandings of the four aspects about inquiry (scientists use varied methods, scientists test ideas, scientists use current knowledge, and investigations may lead to more questions). In fact, the apprenticeship experience appeared to have reinforced apprentices' misconceptions of scientific method in many cases.

Mentors

As with any student–scientist partnership, the role scientist mentors played was critical to the success of the apprenticeship program. Mentors were responsible for guiding the apprentices' acquisition of background knowledge, establishing the research framework for the apprenticeship projects, and providing day-to-day guidance and troubleshooting. Other studies on university apprenticeship experiences for high school students suggest that faculty mentors also affect the manner in which students learned about and discussed science (Bleicher, 1996; Templin, Engemann, & Doran, 1999). Given the seminal role they play in the apprenticeship experience, postapprenticeship interviews with the mentors were used to ascertain their perceptions of what the apprentices learned from their apprenticeships, as well as their own views of the nature of science and science inquiry.

When responding to the question concerning what they believed their apprentice learned about science through the apprenticeship experience, mentors' responses typically focused on learning specific process skills and aspects of experimental design.

> [A8] was involved in a variety of work, from maintaining projects in the greenhouses to field work, including pitfall trapping and mark and recapture, to working with a variety of types of equipment. (M8, EI)

> [A1] gained an appreciation for experimental approach and hypothesis testing, including what hypotheses are and why they are important. He understood the importance of good experimental design, and how it enables us to do what we want to do. (M1, EI)

> How to do it! [Apprentice 10] learned how to do experiments, how to design an experiment, and what an experiment is.... These aren't the two-hour labs they are used to doing in school.... They come in with reasonable, basic skills and I need to teach them how to do experiments and that not everything is known. (M10, EI)

These responses stressing learning techniques and skills matched the emphasis of the apprentices in their interviews. Furthermore, they may explain the apprentices' interview responses in which they adhered to a view of a single scientific method although many of them had participated in observational studies. The scientific method as it is typically presented describes science as an experimental endeavor. Given the mentors' focus on providing their apprentices with short manageable experiences, it is not surprising that the apprentices focused on the scientific method as the defining characteristic of science during their interviews.

Several mentors described opportunities their apprenticeships presented for learning aspects of science inquiry, particularly testing ideas, varying methods, and learning from mistakes.

> I think he has a stronger appreciation for scientific process. Especially the time it takes to do research and the size of the questions that can be reasonably addressed. There is a lot of effort that goes into answering the simplest of questions.... He got a chance to play in a big playground! (M7, EI)

> Probably mostly that it doesn't work the first time. Sometimes its not even trial and error, sometimes it is starting over from scratch. This type of uncertainty can be difficult for some students. (M6, EI)

> She learned that science is not cookbook, which was difficult because she was not used to making mistakes. Even if you are intelligent, you have to get used to making mistakes, too. (M3, EI)

Mentors also discussed the effect of time limitations on engaging the apprentices in more detailed aspects of investigation such as library research and publication, although two mentors discussed inviting their apprentices back to continue with their research.

In response to being asked what apprentices learned as a result of their research experience, mentors made far fewer comments about apprentices learning aspects of the nature of science. Of the 10 participants, only 2 discussed specific aspects of the nature of scientific knowledge that they believed their apprentices learned during their apprenticeships.

> M2: There is no real right or wrong, which sometimes makes this [research] look like a series of mistakes. The students learn that the truth is not out there. Science is not just a march towards goals; the process is more like an adventure. You never really know where you are headed.
>
> Researcher: Did you try to teach this idea to your apprentices?
>
> M2: It's really unavoidable. They see we are constantly going in new directions and get caught up in the action. (M2, EI)

Although this mentor believed that his apprentices would learn that science is not simply a search for objective truth, he did not set out to teach this concept explicitly. Consequently, and despite his beliefs to the contrary, his apprentices apparently failed to pick up on this implicit lesson, as evidenced by their statements concerning the objectivity of science on the VNOS-B and during the follow-up interviews.

Mentor M1 stated that in addition to details and methods specific to the project, he believed it was critical for his apprentice "to understand how research is impacted by societal needs. We are not just doing fun things, spending taxpayer dollars!" (M1, EI). Like the other mentors, M1 assumed his apprentice would learn about the impact of society on the scientific enterprise implicitly through participation in the project and informal discussions among the project workers. Unfortunately, his apprentice failed to learn this lesson, judging from A1's responses to the questionnaires and follow-up interviews.

Although only two mentors volunteered the possibility that their apprentices learned about aspects of the nature of science, other mentors discussed their own understandings of the nature of science in follow-up questioning.

> Things occur that you do not plan for, but it is important to figure out creative ways to utilize what you have to continue the research process. (M3, EI)

> Science is about uncertainty. For many people this is difficult, but it is the basis of how science functions. (M6, EI)

> Scientific research is not always a known quantity. You can't always see ahead of time exactly what to do next. You have to try different things and try to make some sense of what you find. (M10, EI)

The mentors broadened their discussions of the nature of scientific endeavors to include desirable values and ethical qualities of scientists.

> It is important to have a good work ethic. That includes being enthusiastic, hard-working, and observant in order to produce high-quality work. (M3, EI)

> Research often has times when things simply do not work out. It is important to persevere. That is a hard, but key, lesson to learn. (M7, EI)

> Students need to develop an appreciation for science, including that science is not just done for fun, that they are actually spending taxpayer dollars. (M1, EI)

These responses suggest that although the mentors may have had a degree of understanding of the nature of science derived from their own experiences in science, they did not necessarily share these understandings with their apprentices.

When asked whether they explicitly taught their apprentices anything about the scientific enterprise, the mentors stressed that the way to learn about science is to do science. They also stressed that this was the way scientists traditionally learned about science, by actively participating in the research process.

> Most of these things are learned by osmosis. This is the way I did it, and this is the way others have done it. This is an environment in which to flourish or flounder. (M7, EI)

> You learn about science from participating. She learned science for herself. (M6, EI)

> Seeing is believing. This is the way to learn the basics. (M9, EI)

In general, the interactions between mentors and apprentices focused on problem solving related to the projects, and little time was spent on explicitly discussing general attributes of science. Analysis of the mentor interviews indicated that few provided any explicit instruction regarding either the nature of science or scientific inquiry. The small amount of direct instruction provided by the mentors dealt primarily with science processes directly related to the projects the apprentices were working on. Discussions between mentors and apprentices usually centered on immediate concerns with the data collection and procedures of the project. Most mentors did not intentionally discuss their own views about the nature of science and inquiry, choosing instead to "let them learn about science the way we did, by doing it." (M7, EI)

Discussion and Implications

Developing adequate understandings of the nature of science and scientific inquiry have been perennial instructional objectives of science education for at least the past 5 decades. Although little success has been documented for either of these objectives, the *National Science Education Standards* (NRC, 1996) and *Project 2061* (AAAS, 1989, 1993) continue to emphasize the importance of developing adequate understandings of the nature of science and scientific inquiry, linking them to the overarching goal of scientific literacy. This investigation characterized the effects of the (primarily implicit) messages students receive during 8-week science apprenticeships on their knowledge about the nature of science and scientific inquiry.

According to the mentor scientists, students were exposed to a wide range of scientific investigation experiences. In particular, scientists described their students as engaged in the development of research methods, data collection, and data interpretation. In general, however, students were not given opportunities to develop research questions for these investigations, an omission that appears typical for such time-limited programs (Barab & Hay, 2001; Moss et al., 1998). Furthermore, scientist mentors assumed that these students would come to understand science by doing science. This is not surprising, as it is generally assumed that students will learn not only to do science, but also to learn about essential aspects of science by doing science. In short, it appeared that the scientist mentors believed that implicit instruction on these topics would achieve desired (if unstated) educational outcomes. Unfortunately, most students exhibited little change in their understandings of the nature of science and their understandings about scientific inquiry.

With respect to the nature of science, students' expressed understandings (as demonstrated in both pre- and postapprenticeship assessments) were tenacious and for the most part did not change as a result of their apprenticeship experiences. In line with currently accepted views of the nature of science, they believed that scientific knowledge is based on empirical evidence and that theories can change. However, these beliefs tended to be superficial. Students ascribed tentativeness to lack of information and for the most part did not understand that it is possible for different interpretations of the same data to be valid. Furthermore, students possessed the misconceptions that with more evidence, scientific theories can eventually be proven, and that scientific laws are absolute. Finally, the apprentices tended to limit the role of creativity in their understandings of science by restricting it to the initial stages of experimental design.

With respect to scientific inquiry, students clearly learned certain inquiry skills, especially with regard to specific tasks related to their apprenticeship. However, students also exhibited a strong belief in a single scientific method although many participated in research projects more closely aligned with descriptive than experimental research. It is especially important to note that the sample of students for this investigation is not representative of the population of secondary students. Students selected for this apprenticeship program are recognized as high-ability science students by any criterion. Still, the lack of major changes in views clearly indicates the lack of a discernible influence of the program, even for these high-achieving students.

Although the results of this investigation do not support the intuitive assumption that students will learn about science simply by doing science, the data offer some degree of hope. One apprentice in particular (A2) demonstrated a clear shift in her views of at least one aspect of the nature of science. In addition, Apprentice A2 clearly attributed this change in views to her apprenticeship experience. The understanding that theories can change not only as new evidence is brought to light but also as a result of new ways of looking at existing evidence is an important component of understanding scientists' work. Few secondary students and prospective science teachers fully grasp the idea that scientists use creativity in viewing the same data in new ways. Yet, Apprentice 2 articulated an informed view of this aspect after her apprenticeship:

> I just realized through my apprenticeship how often multiple theories are in existence at the same time. . . . I think at any one time in any field there are multiple theories, multiple ways of explaining why things occur. If one group of people interpret current knowledge to mean one thing, and another group interpreted the same knowledge to mean something else, then they could develop very different theories.

Much of the value of this research rests in the anomalies in the data, just as is sometimes the case in scientific research. Thus, it is worth exploring the nature of Apprentice A2's experience and her thoughtful reflections to gain insight into possible factors that could lead to others' acquiring enhanced views of the nature of science and scientific inquiry.

Although we cannot claim a causal relationship, three aspects of this apprentice's experience appear to be particularly important: (a) the nature of the work during her apprenticeship (nonexperimental and highly correlational), (b) the mentor scientist's interactions as evidenced by his field-based commentary, and (c) the intern's opportunity to reflect on the experience.

First, Apprentice A2 engaged in research related to the reproductive biology of snakes, and fieldwork with an expert working on the problem of mutated frogs. This nonexperimental fieldwork study involved finding correlations between physical conditions of snakes and reproduction. Furthermore, the project provided a high degree of epistemic demand given that Apprentice A2's beliefs about theories were challenged by the work she performed. Second, the mentor made explicit connections situated within the fieldwork. The mentor explicitly discussed how scientists might explore different ideas at the same time, in the context of his study related to mutated frogs. Third, by writing the pre- and postquestionnaires followed by in-depth interviews, the apprentice was encouraged to reflect on the relationship between the work of her apprenticeship and knowledge generation in science. Whereas Apprentice A2, by her own admission, was prone to reflect on such issues, one other apprentice (A3) described a minor change in her view of science as a result of reflecting on the VNOS-B instrument itself.

These results emphasize the importance of epistemic demand and systematic reflection upon one's actions. Epistemic demand alone may not be enough to change students' views of science and inquiry because it appears that many students can focus on the task at hand without considering the larger context and implications of what they do. Consider the apprentices in this investigation who clung to the view of a single scientific method, despite their experiences in scientific investigations that were descriptive in nature and did not follow the traditional steps of the scientific method. Thus, experiences in authentic science, even those with potential for a high degree of epistemic demand, may be necessary but not sufficient to elicit changes in students' conceptions of science and inquiry. As Mary Budd Rowe (1978) aptly reminded those who would cite Dewey regarding learning by doing, ''John Dewey never said that we learn by doing. He said that we learn by doing and by *thinking* about what we're doing'' (p. 216). Students need to be encouraged to connect the science they are doing in and out of the classroom to the scientific enterprise. Only then can they hope to develop understandings of the abstract and complex nature of science and inquiry.

Science educators may prove to be an important component of successful apprenticeship programs aimed at overcoming misconceptions about the nature of science and scientific inquiry. For example, science educators could provide orientation for scientist mentors to alert them to common nature of science misconceptions and scientific inquiry, as well as to the importance of explicit instruction in overcoming these misconceptions. Another approach would be for science educators to conduct a seminar for student apprentices, in which they are encouraged to make explicit connections between the work that they are accomplishing and the scientific enterprise. Our understanding of the roles of implicit and explicit messages in the development of desired conceptions of the nature of science and scientific inquiry is currently evolving. As our knowledge grows, science educators will be in a better position to help maintain an appropriate balance between implicit and explicit messages in both classroom instruction and research experiences.

Recent research indicates the need for teacher educators to provide opportunities for preservice teachers to reflect on their actions explicitly in such a manner that the nature of science and scientific inquiry are brought to the forefront (Abd-El-Khalick et al., 1998). In a related investigation (Schwartz, Lederman, & Crawford, 2000), preservice teachers worked in an active scientific laboratory in an effort to improve their understandings of nature of science and scientific inquiry. Although some success was noted, changes in views were directly attributed to reflective debriefing sessions held by the researchers and not the research experience. Despite Mentor M7's best intentions as reported earlier in this study, it seems clear that students (K–12 or adults) do not learn about the nature of science and scientific inquiry by osmosis. When students only do science, it is the doing, and only the doing, that is explicitly addressed and learned. Although it may prove beneficial for teacher education programs to include authentic scientific inquiries as required elements of their programs, it is critical that the programs provide courses or other experiences that explicitly debrief these science experiences in terms of the nature of science and scientific inquiry. Without such experiences, future teachers are unlikely to develop the understandings about nature of science and scientific inquiry that make current science education reform efforts unique from those of the past.

Appendix A: Sample Apprenticeship Profiles

Sample Apprenticeship Profile for Apprentice A2

The apprentice worked in a zoology laboratory studying reproductive biology of snakes. The apprentice's project focused on the relationship between body condition and reproductive capability. This research was part of a larger study investigating natural influences on snake population size, with possible implications for control of invasive snake species. The apprentice assisted in collecting snakes and maintaining them in captivity (feeding and general animal husbandry). To draw connections between physical characteristics and reproduction, the apprentice marked the snakes and collected data on weight, length, temperature, and number (of births). The apprentice conducted radioimmunoassays to monitor endocrine changes and kept a research journal. During the project, the apprentice repeatedly analyzed data and discussed results with the research team. Modifications were continually made based on the apprentices' observations and inferences.

The apprentice also volunteered to assist with a separate amphibian project and worked with graduate students conducting a variety of research projects. In addition to presentation at the conference concluding the apprenticeship, it is anticipated that results of this project will be presented at a national science meeting and published in a science journal.

Sample Apprenticeship Profile for Apprentice A6

The apprentice worked in a plant pathology laboratory investigating how bacteria can degrade harmful chlorinated pollutants into less toxic compounds. This was part of a larger study investigating the aerobic metabolism of chlorinated aliphatic hydrocarbons by butane-using microbes. The apprentice conducted experiments on degradation rates using a variety of different media. To study degradation of the pollutants, the apprentice grew bacterial cultures, assessed their growth using a spectrophotometer, and prepared the cultures for the degradation assays using an ultracentrifuge. The apprentice then prepared buffer solutions for the degradation assays and performed the assays using electron capture and flame ionization detector gas chromatographs. This was followed by a protein assay to roughly estimate culture size.

The apprentice then entered and plotted data on computer, and analyzed the data to make alterations in the experimental design. Results were reported at a biweekly research group meeting and at the conference at the end of the apprenticeship. It is anticipated that results of these experiments will be published in a science journal.

Both mentor and apprentice interview responses verified that these apprentices were actively involved in a high degree of scientific inquiry during their apprenticeships. Most apprentices experienced a wide range of scientific inquiry, including experimental design, data acquisition, data analysis, and reporting results. In addition, the apprentices reported using a variety of methods to answer research questions, including modeling, experimentation, and correlational studies.

Appendix B: Modified VNOS-B Questionnaire

1. After scientists have developed a theory (e.g., atomic theory, kinetic molecular theory, cell theory), does the theory ever change? If you believe that scientific theories do not change, explain why and defend your answer with examples. If you believe that theories

do change: (a) Explain why. (b) Explain why we bother to teach and learn scientific theories. Defend your answer with examples.

2. What does an atom look like? How certain are scientists about the structure of the atom? What specific evidence do you think scientists used to determine the structure of the atom?
3. Is there a difference between a scientific theory and a scientific law? Give an example to illustrate your answer.
4. What is the scientific method? Do all scientific investigations follow the scientific method? Defend your answer.
5. Scientists perform experiments/investigations when trying to solve problems. Other than in the stage of planning and design, do scientists use their creativity and imagination in the process of performing these experiments/investigations? Please explain your answer and provide appropriate examples.
6. Some astronomers believe that the universe is expanding; others believe that it is shrinking; still others believe that the universe is in a static state without any expansion or shrinkage. How are these different conclusions possible if the astronomers are looking at the same experiments and data?
7. A person interested in botany collected specimens from the Andes Mountains of Venezuela and the volcanoes of the Canary Islands. Based on these specimens and his extensive field notes, he developed the concept of altitudinal zonation, which describes how plant species found at sea level differ significantly from those found at high elevations. Would you describe this person's work as science? Please explain.
8. You decide to inventory the birdhouses in your neighborhood as an after-school project. During this inventory, you locate a total of 34 birdhouses, only 14 of which are being used by nesting birds. The others are currently unoccupied. You decide that you would like to know why some of the birdhouses are occupied and others are not. How would you conduct this study?

Appendix C: Apprentice Exit Interview Questions

1. Please describe what you did in your apprenticeship.
2. Did you have an opportunity to conduct your own research project?
3. What did you mean by your response to question number (refers to a specific question on the questionnaire)?
4. Did your views about science change as a result of your apprenticeship experience? In what way? or Why not?
5. What kinds of things did you and your mentor talk about?
6. Did your mentor ever talk to you about the kinds of things on this questionnaire? Please explain.
7. What did you learn from your apprenticeship experience?

Appendix D: Mentor Interview Questions

1. Briefly describe the apprenticeship.
2. During the apprenticeship, did you modify your original plans? If so, in what way? Why?
3. What do you think the apprentices learned about science by completing this apprenticeship?
4. Did you explicitly teach your apprentice anything about science during the apprenticeship? If so, what? How?

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