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ABSTRACT

Science educators often assume and expect that students who are actively engaged in scientific inquiry should develop more accurate understandings of science and the construction of scientific knowledge. However, this assumption, while intuitive, has not been validated. This paper reports on a study that sought to determine the impact of an 8-week science apprenticeship program on a group of high ability students' understandings of the nature of science and scientific inquiry. The results of this investigation do not support the intuitive assumption that students will learn about scientific inquiry and the nature of science simply by doing science. (Contains 21 references.) (WRM)

Just Do It?
The Effect of a Science Apprenticeship Program on High School Students' Understanding of the Nature of Science and Scientific Inquiry

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JUST DO IT? THE EFFECT OF A SCIENCE APPRENTICESHIP PROGRAM ON HIGH SCHOOL STUDENTS' UNDERSTANDING OF THE NATURE OF SCIENCE AND SCIENTIFIC INQUIRY

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Recent reforms in science education have increasingly emphasized the importance of students developing current understandings of the nature of science and scientific inquiry (e.g., American Association for the Advancement of Science, 1989; National Research Council [NRC], 1996). However, research studies have consistently shown that students' views are not in line with the more recent conceptions of either the nature of science (Aikenhead, 1973; Bady, 1979; Broadhurst, 1970; Mackay, 1971; Miller, 1963; Rubba, Horner & Smith, 1981), or scientific inquiry (Welch, 1979). A common recommendation among these and other studies has been for educators to provide students with opportunities to "do science" through in-class science projects or extra-curricular work with scientists (Gallagher, 1991; NRC, 1996; Schmidt, 1967; Tobin & Gallagher, 1987). After all, it seems reasonable that students who are actively engaged in scientific inquiry should develop more accurate understandings of science and the construction of scientific knowledge.

Involvement in scientific inquiry can range from brief classroom laboratories to lengthy projects in research laboratories. The assumption has been repeatedly made that the more authentic the research experience, such as an apprenticeship guided by science professional, the more likely students will learn about aspects of scientific inquiry (Ritchie & Rigano, 1996). Hodson (1993) stated that: "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) Programs have sought to place students in research laboratories or special programs to develop a broader and more complete understanding of science (Cooley & Bassett, 1961).

But is this approach as reasonable as it first appears? The suggestion that simply engaging students in scientific inquiry will improve their views of the nature of science and scientific inquiry is ultimately based on the assumption that students' can learn these complex constructs implicitly through "doing science." This assumption, while intuitive, has not been validated. In fact, a review of research on improving college students' understandings of the nature of science has recently concluded that students are unlikely to gain the desired understandings through implicit instruction alone (Abd-El-Khalick & Lederman, 1998).

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. The main questions of the investigation were (a) What are the student's understandings of the nature of science before entering an apprenticeship program? (b) What are the student's understandings of scientific inquiry before entering an apprenticeship program? (c)

What impact (if any) did the apprenticeship program have on the student's conceptions of the nature of science? (d) What impact (if any) did the apprenticeship program have on the student's conceptions of scientific inquiry?

The Apprenticeship

The apprenticeship program has a seven-year history of placing students in science laboratories throughout a Pacific Northwest state. Apprentices worked in laboratories for an eight-week period during the summer, usually between their junior and senior years in high school. Interested students underwent a rigorous application process that involved an extensive written application and 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 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 on-going projects, or conducted a spin-off research project of interest. The mentors and the laboratory workers provided guidance throughout the apprenticeship experience.

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. Mentors were encouraged to engage the apprentices in all aspects of research, and not merely the "grunt work" often assigned to temporary laboratory employees. Several of the science inquiry skills outlined in the National Science Education Standards (1996) were components of the apprenticeships, particularly dealing with 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, most requiring apprentices to learn a significant number of procedures and skills. Sample apprenticeships are described in Appendix A.

Method

Ten volunteers (grades 10-11) were purposely selected from the 18 high school students participating in a science and engineering apprenticeship at a Northwest university. These apprentices participated in apprenticeships previously identified as providing opportunities for a high level of inquiry (Bell & Blair, 1997). Each high school apprentice worked within a laboratory full-time for 8 weeks during the summer, with exposure to research design, data collection, and data analysis.

Prior to the first week of their apprenticeship, the apprentices were administered an open-ended questionnaire to assess their conceptions of the nature of science and scientific inquiry. The questionnaire focused on eight aspects of the nature of science considered appropriate for secondary students (Abd-El-Kalick, Bell, & Lederman,1998; Smith et. al., 1997). The aspects of the nature of science assessed were the tentative and empirical nature of science; subjectivity, creativity, and the role of social and cultural contexts in science; observation versus inference; and the functions of and relationships among theories, hypotheses, and laws. Additionally, the questionnaire assessed students understandings of scientific inquiry gleaned from Benchmarks for Science Literacy (AAAS, 1993) and National Science Education Standards (NRC, 1996): six aspects of doing inquiry (formulating questions; designing investigations; dealing with data; constructing explanations; testing explanations against current scientific knowledge; and communicating results) and four aspects about inquiry (scientists use varied methods; scientists test ideas; scientists use logic, higher-order thinking, and current knowledge; and investigations may lead to more questions). The same questionnaire was administered as a posttest at the end of the 8-week apprenticeship in order to determine whether the students' conceptions of science changed during their apprenticeship experiences (See Appendix B).

Semi-structured exit interviews provided the apprentices with an opportunity to describe the nature of their apprenticeship experiences and to elaborate on their written questionnaire responses (see Appendix C). The interviews provided insight into students' conceptions of the nature of science and scientific inquiry. Additionally, the interviews provided the researchers with the opportunity to explore the role of the research experiences in shaping the apprentices' concepts of science.

Exit interviews were conducted with the scientists who served as mentors for each of the science apprentices. The mentors were interviewed at the conclusion of the 8 weeks to provide additional information about the apprenticeships and the degree of explicit instruction related to the nature of science and scientific inquiry. The mentors were asked a series of questions (See Appendix D).

Follow-up questions were used to obtain more detailed responses during both apprentice and mentor interviews. The interviews were audiotaped and transcribed. All four researchers analyzed the questionnaire responses and interview transcripts. Prior to 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 compared in order to establish inter-rater agreement on the categorization of the apprentices' beliefs regarding the nature of science and scientific inquiry. Better than 95% agreement among the three researchers was achieved. The transcriptions and questionnaire responses were coded, read and reread to search for categories pertaining to the nature of science and scientific inquiry.

The analysis focused on generating in-depth profiles of the participants' views and the aspects of scientific inquiry experienced during their apprenticeships. Each participant was treated as a separate case. Questionnaire and interview data were used to generate a summary of the participants' understandings of the previously discussed aspects of the nature of science and scientific inquiry. Finally, the researchers compared each participant's pretest and posttest summaries to determine the degree of change that occurred during the apprenticeship.

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.

The Nature of Science

Changes in the Apprentices' Understandings

Comparison of the 10 apprentices' responses to the pretest and posttest questionnaires and posttest interviews indicated few changes in their understandings of the nature of science over the course of the eight-week apprenticeship program. In fact, the views of only three apprentices changed appreciably, and only one of these attributed her change in view to the apprenticeship program. This particular apprentice developed an understanding of how common it is for multiple theories to co-exist:

Researcher:

So, did your views of theories change over the course of your apprenticeship?

Apprentice:

Yeah. 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. (2)*

Researcher:

That's a pretty interesting idea-where did you learn that?

Apprentice:

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 field work 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. (2)

It should be noted that this apprentice stood out from the other apprentices in that she was extraordinarily reflective, as indicated by her many references to her apprenticeship as a source for examples during the interview. She even jokingly referred to the fact that her friends at school called her "the Thinker".

A second apprentice changed his view of the relationship of theories and laws over the course of the summer. In the following interview excerpt, he describes a shift from a hierarchical view, where theories become laws when proven, to a view that theories and laws are different types of knowledge:

Researcher:

On the posttest you said," there is a difference, but I don't know what it is..."

Apprentice:

Yeah, Well, I have read about it in a science book since then.

Researcher:

Oh, in the last week or two?

Apprentice:

Yeah. Well, the difference is that a scientific law is something that happens, you know. If you drop something, it is going to fall. And a scientific theory is explaining why the object falls.

Researcher:

OK- so... you didn't really know that before you took your chemistry class this fall?

Apprentice:

No, I just realized that. I thought that a law, a scientific theory is that they were not quite sure about it. Like about 99% sure. And I thought that a scientific law was that they were absolutely sure.

Researcher:

O.K. So now, do you think that theories turn into laws?

Apprentice:

Ah, no. Because the theory is the explanation of why something happens, and a law is that something happens.

The apprentice made it very clear that his change in views concerning the relationship between theories and laws came from reading his chemistry textbook, rather than his apprenticeship experience.

The third change in understandings of the nature of science came from an apprentice whose views appeared to shift from an absolute to a more tentative view in regard to atomic theory. In her response to the second item of the pretest questionnaire, she stated:

> *Scientists are very sure about the structure of the atom... they probably did a lot of research using strong microscopes to determine the structure of the atom. (3)*

This answer describes the atomic model as something that can be viewed directly and appears to confuse the model, which is based on inferential evidence, with reality. In her posttest questionnaire response, the apprentice speaks more of indirect evidence:

> *Scientists are pretty certain that they have discovered all aspects of the atomic structure, but new evidence could always come up. Scientists relate the actions of the atom to the location of certain things in the structure. For example, scientists think the electrons are in fields around the nucleus because they are accessible enough there to cause static electricity. (3)*

When asked during the interview to elaborate on this apparent change, the apprentice explained:

> *I did kind of change my opinion. The first answer I gave about the atom, I don't think anyone really knows or has seen an atom, because it's not something you can see. My second answer was trying to explain certain ways that they can prove that it looks that way without really knowing what it looks like. So, they're doing experiments with static electricity and things that involve atoms and electrons and stuff. (3)*

When queried about the source of this change, however, the apprentice clearly indicated that the change in her responses was the result of reflection on the pretest, rather than any implicit or explicit instruction she experienced during her apprenticeship:

Researcher:

> *Is that change something that occurred because of your apprenticeship, or something else?*

Apprentice:

> *It's 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. (3)*

In conclusion, the only change of apprentices' understandings of the nature of science that can be attributed to the apprenticeship experience is the view that Apprentice 2 developed concerning the coexistence of multiple competing theories. No other apprentice experienced any changes in their understandings of the nature of science attributable to their participation in the intensive and authentic eight-week apprenticeships.

Views of the Nature of Science

Following are descriptions of the apprentices' views of the nature of science with representative excerpts from their pre-and posttest questionnaires and interview responses.

The Empirical Basis and Tentativeness of Science

All of the participants expressed the belief that science is empirically based. For example, in response to the interviewer's question about the difference between an idea and a scientific theory, one apprentice stated:

> *An idea is just what something thinks, and a theory actually has evidence to back it up. The Theory of Evolution has lots of physical evidence to back it up-the fossil record and I guess similarities between different organisms. (7*

Other expressions of the empirical nature of scientific knowledge were in conjunction with explanations for the tentative nature of scientific theories. Specifically, all the apprentices noted that theories change in light of new evidence. The following are representative of the apprentices' comments:

> *Theories change because we have new technologies that allow us to see farther into space or to see smaller particles. (10)*

> *Theories do continually change. As more experiments are done and more results and conclusions are drawn, most theories are modified or updated. Although it is uncommon, some theories are greatly altered or proven wrong. (9)*

Only 2 of the 10 apprentices cited new ways of looking at existing evidence as a reason that theories change:

> *Theories change because of new evidence and new ways of looking at the evidence that's already there. This is part of the normal scientific process. (1)*

> *I don't think new knowledge is the only thing that would make a theory change. ..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. You know, it's the second group of people that come along and look at the knowledge and come up with a theory that seems to make a lot of sense to other people in the field, then it could be that the theory is changed and the new one would be accepted. No new knowledge is necessary. (2)

Finally, while two apprentices believed that laws, as well as theories, are tentative:

Many situations in physics can be explained with the laws of physics (gravity, thermodynamics, etc.), but there is also quantum mechanics where some of the theories and laws are not useful anymore. (8)

...a law might be still proven wrong in the long run. (5)

the majority of the apprentices believed laws in science to be absolute:

Theories can change, or else they would be laws. (7)

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. (2)

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. (3)

<u>The Relationship Between Theory and Law</u>

In addition to the misconception that scientific laws represent absolute knowledge, many of the apprentices expressed the misconception that theories and laws are the same kind of knowledge, separated only by the degree of certainty ascribed to them. In the apprentices' views, theories become laws over time as enough evidence is collected for them to be proven:

OK, um, 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. (5)*

From my understanding, an hypothesis is sort of, the lowest down on the level...a theory has been proven more, with less fault. It is just more concrete than an hypothesis, and a law is even more so than a theory. It is something, such as gravity, that is proven everyday. It has never been proven wrong, so it has become a law. (9)
A theory turns into a law, but most of the time it will remain a theory. It will turn into a law when they are positive that is what is right. (7)

This hierarchical view of the relationship between laws was not held by all of the apprentices, however. Four of the apprentices demonstrated understandings that laws are statements or descriptions of patterns in observable phenomena, while theories provide explanations for those phenomena.

Theories are ways science explains the world around us. From what I understand, laws just describe what is happening. So, the law of gravity describes that an apple falls down, but it doesn't explain why. (1

Laws describe what happens. A theory tries to give a reason for what happens and a law just describes it. (4)

However, being able to state a particular view did not necessarily mean that they were able to apply it. For example, one of the apprentices was able to describe the relationship between laws and theories. However, when she applied it to her apprenticeship project, she incorrectly labeled the relationship that she developed between a snake's mass per unit length and its gravity as a theory:

What I've been taught, at least, is that laws are all observable or immediately obvious. And I'm not sure whether that's true or not, but that's what I've been taught. The effect of gravity is immediately obvious; it's always there. The theory that we developed about garter snakes was that a snake's mass per unit length will determine the likelihood that it will reproduce in a given year. And that's got a lot of exceptions. Like, some very unhealthy snakes will reproduce in a given year. And that happens. It can't be a law. At least the theory that we developed can't. It can't be a law because it's not consistent. It's consistently broken, actually. I think our theory is correct, but it's not like a given... As far as I know, laws don't change because they're facts. They're not really explanations. That's what theories are. Theories are more explanations, laws are facts. (2)

<u>Observation and Inference</u>

The second item on the open-ended questionnaire was concerned with the model of the atom, how certain scientists are about that model, and what kinds of evidence they use to support it. The primary focus of this item was the difference between observation and inference. A common response to this item is that scientists have viewed the structure of atoms directly using powerful microscopes. This reference to direct evidence reflects a misunderstanding of the inferential nature of scientific models. Only 2 of the 10 apprentices expressed this view:

I believe that scientists have very little doubt about what the nucleus looks like because they can detect them with different microscopes. (6)

Scientists probably did a lot of research using strong microscopes to determine the structure of an atom. (3)

It should be kept in mind that apprentice 3 changed her response on the posttest and interview to reflect a more tentative view, i.e., that atomic models are based on inference, rather than observation. As described earlier, she explained this change as the result of her reflecting on the questionnaire, rather than her experiences in the apprenticeship program.

Most of the apprentices, however, demonstrated some understanding of the inferential nature of the atomic model:

> *There are different ways to diagram atoms, like the Bohr model, or models showing the shapes of different orbits in the electron cloud. Of course, these are just representations. (6)*

> *As far as I know, it's still not possible to actually see an atom. I think [the structure] is mostly determined by how atoms behave--how they combine, or how they don't combine. As far as I understand, there's a lot of theory, too. And I would imagine that would be the case anytime you can't actually see what you're studying. (2)*

> *Scientists are never certain that any one particular model can last. A lot of it is based on evidence that we can't really see, like in Rutherford's investigation. I think that scientists developed the current quantum model by using an array of instruments...to develop a probability field. (7)*

Creativity and Subjectivity

All of the participants ascribed some role for creativity in the construction of scientific ideas. For example, while all of the apprentices saw experimental design and developing methodology as creative endeavors, some believed that creativity should be avoided during data interpretation:

> Apprentice:

> *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 sorta 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 sorta have creative answers to what their data is showing.

Researcher:

So what about that? Is that O.K.?

Apprentice:

No. If you have data, you should go with what the data says. You could create a new hypothesis... They could use their creativity and imagination in that. (10)

Clearly, this apprentice expressed an absolutist/positivistic view of data interpretation. Most apprentices, however, were willing to ascribe a role for creativity and imagination in the interpretation of data:

Apprentice:

If there wasn't creativity, you wouldn't be able to come up with anything at all. If you have creativity, you look at the data and if you think you see something in it, then you investigate it further. (7)

I think that [creativity] is a big part of science, because, I think, that actual discoveries have been made, not because scientists follow the scientific method, but because they are creative... they have to look beyond what is right in front of them. (5)

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?

Apprentice:

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. (2

One important aspect of the apprenticeship experience was the conference at the end of the summer where each apprentice shared the results of his/her project with the other apprentices and mentors. An important consideration for the apprentices at this time was how best to present and display their project results. Consequently, a few of the apprentices cited presenting data as a place in a science investigation where creativity plays an important role:

Apprentice:

I think, probably, communication is where it comes in a lot. What is the best way to communicate to the public? You have to be really creative to get your point across. (4)

Researcher:

Is it possible to use creativity in other aspects of the investigation?

Apprentice:

Oh, yeah. That's another place that creativity is used is in displaying the data. (3)

While there certainly is a place for creativity in communicating the results of an investigation, this is generally not considered part of the scientific process itself. Additionally, there can be a real danger if students take this idea too far, since one has to be careful that the creativity involved in communicating the results does not distort or detract from the results themselves.

The apprentices also suggested that subjectivity contributes to the tentative nature of science. Most dismissed the view that science as completely rational and objective:

Every human has their own way of looking at things, it's subjective. They see the world a certain way. They get this information, they interpret it the way they see it. These different conclusions are possible because the world is viewed differently by different people. I believe there is an entirely right answer in this case, but I don't know what it is. (1)

Once you develop an idea you tend to be biased. Everybody's mind functions differently. So you are going to look at it differently, So they are going to think that this is their idea, and it is going to be pretty hard to convince them otherwise, if they are sure about it. I mean, scientists are human. (7)

A few students , however, held on to a more objective view. Some apprentices directly stated their belief that science should be objective:

Apprentice:

I could look at a picture and think that it is beautiful, and you could look at a picture and think that it is ugly. You know, even though it is still the same picture. And I think that scientists still do that, even though they are not supposed to.

Researcher:

Are scientists supposed to be objective?

Apprentice:

They are. but I think it is really hard to be completely objective. I mean we all have our views. If the data were more accurate, I don't think we would have as much debate about whether it was expanding or not. (10)

Others indicated an objective view by emphasizing that the different interpretations were the result of looking at different data:

Apprentice:

I guess it could be conflicting data, like one astronomer looks at stars that are spreading out and another astronomer looks at planets getting closer... (4)

The universe is huge. It's so big that we can't see most of it or comprehend where the end is, and because of this, different people, or what they call theoretical physicists, I guess, don't observe it the same way. They can observe parts of it, but they obviously don't come to the same conclusion. (2)

Researcher:

How can they infer different things if they are looking at the same data?

Apprentice:

I'm not sure...I guess they could look at microcosms and see what is happening in, like, smaller models. I suppose they could see different things if they were looking at different galaxies or solar systems. (9)

A few indicated that the different interpretations were due incomplete or inaccurate data:

The data is inconclusive or misinterpreted. More studies should be done. (10)

If we had all the data, then we would know. But it is clear that we are missing something. (6)

Still others suggested that some of the scientists were misinformed or even dishonest:

Researcher:

What about a person's background might cause him/her to interpret something differently?

Apprentice:

Well, perhaps one scientist does not have as strong of a background in astronomy as the other, and so they didn't really know what they were looking at. So, they just interpreted the results differently than someone who had been studying astronomy all their life and knew exactly what the numbers meant. (3)

I think people can distort data in many ways. What if the universe is expanding during some part of a year, shrinking during others, or even remaining constant during some time period. 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. (8)

The Social and Cultural Embeddedness of Science

The effects of the social and cultural contexts in which scientific investigations are embedded were almost entirely overlooked by the apprentices in this study. As previously demonstrated, many of the apprentices cited "different interpretations" as the reason that the astronomers in item seven of the questionnaire came up with different conclusions about the ultimate fate of the universe. When probed about the source of these different interpretations, all of the apprentices cited personal beliefs/bias. Only one apprentice volunteered that influence outside the individual might play a role in data interpretation:

I think it's because sometimes their company wants it to be a certain way, they want to have this theory proved, or whatever their personal agenda is. Let's see, if someone is really religious they'll think creationism is right, if someone is an atheist, they'll think evolution is right. So, personal belief or the company's agenda. (4)

In summary, despite participation in an authentic, inquiry-oriented science apprenticeship program, none of the 10 participants were found to have mastered all seven aspects of the nature of science described at the beginning of this paper. In particular, no single apprentice appeared to possess "acceptable" understandings of any more than four of these seven aspects. In general, the apprentices appeared to understand the empirical basis for scientific knowledge, the tentative nature of hypotheses and theories, and the role of creativity in scientific investigation. A few appeared to posses an instrumentalist view of the atomic model. Fewer still were able to articulate the differences between scientific theories and laws, and almost none attributed a significant role for social and cultural influences in the development of scientific knowledge.

When the participants were asked about the sources of their understandings (whether "acceptable" or not), references to their apprenticeships were conspicuously absent. 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 salient:

> *Working in the ASE 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. (8)*

Scientific Inquiry

Changes in the Apprentices' Understandings

Apprentices noted that they learned more about doing science due to participation in their apprenticeships, as discussed in detail below. However, few apprentices exhibited changes in their knowledge about scientific inquiry, despite involvement in laboratory investigations over a sustained length of time.

The interviews of a few apprentices provided evidence of the beginnings of change in thinking about the real work of scientists. For example, Apprentice 2's view of the scientific method remained intact following her apprenticeship, but she appeared to be wavering in this belief. Early in the interview this apprentice appeared to believe in a single scientific method. However, later she indicated that her view of science had changed over the summer to a more general view.

> *Yeah, I think that my concept of what science is has changed. I kind a think that I have a more general view of science than I would have, if you had asked that question before my apprenticeship... I know have a more general view because science is about the real world. It is not just what goes on in labs. (2)*

As stated in the previous section, this apprentice acknowledged that she was particularly thoughtful. Her exceptional ability to reflect, combined with the observational nature of her field work, contributed to her ideas of a more general view of science.

In most cases, the apprentices' previous understandings of scientific inquiry were reinforced by their work with their mentors. Some apprentices stated they acquired an in depth understanding of lab safety, following procedures, and the need to be careful in collecting data.

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. (3)

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. (1)

One might predict that apprentices involved in descriptive work and correlation studies, versus experimentation, would more likely change their views of inquiry. However, this was not the case. For example, apprentice 1 maintained his belief in a single scientific method. "As far as I know all scientific investigations include controlling variables." This idea of a single scientific method was substantiated in his response to the birdhouse question, "This is following the scientific method. I'm controlling variables...I'm doing experiments."

Yet, this same student participated in a descriptive study of a beetle in an old growth forest. Although his apprenticeship experience involved finding patterns, Apprentice 1 held onto his earlier beliefs. Apprentice 1 viewed his apprenticeship study as a precursor to the real scientific investigation and something less than science, "In my experiment we were mostly describing what we found. We did not have much of a chance to put controls on different things."

Acquiring Abilities to Do Inquiry

Apprentices and mentors reported that the apprentices learned many new ways of doing science. Apprentices were actively engaged in research, particularly data manipulation, construction of explanations, testing of explanations, and communicating results.

> *I did the actual data collection, and then kind of looked at that, trying to figure out what it might mean, then went deeper into it. (2)*

> *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. (10)*

> *So in my experiment, I had the title, and I had my objectives, what I was trying to accomplish, looking at the effect of wood species and the different solutions on the growth of the fungus...then I made graphs and I analyzed the data and made conclusions about it. So, I basically followed the method. (8)*

Some of the apprentices had the opportunity to test their explanations, primarily in response to emerging "problems:"

> *We had to do a quick save to figure out how to salvage the experiment and explain the data (4).*

Apprentices learned about making sense of their data, and using evidence to construct explanations.

> We tried to explain why we got the results that we did and we both had ideas about that (5)

Additionally, several of the apprentices reported that they acquired abilities to do various aspects of science inquiry as a result of their participation in the program.

I have learned more about the nature of conducting experiments and running tests than I ever would in a science class. (7)

Fewer references were made to formulating research questions or designing investigations. This is not surprising in that most of the apprentices joined research already in progress, missing the design portion of the project.

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. (8)

Apprentices modified existing experiments as illustrated by this comment.

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. (7)

The apprentices had rich experiences in carrying out the scientist-designed experiments. However, the summer apprenticeship generally afforded few opportunities to participate in the creative work missing in many high school science laboratories-- the work of formulating broad and ill-structured questions, refining and refocusing these research questions, and designing the studies.

Developing Knowledge About Scientific Inquiry

While the apprenticeship experience appeared to reinforce and enhance students' abilities to do scientific inquiry, it did little to improve their knowledge about scientific inquiry. This is well-illustrated by the apprentices' adherence to the single scientific method misconception.

Seven of the 10 apprentices referred to a single scientific method in their questionnaire and interview responses:

> *The scientific method is a step-by-step process to solving a problem...scientific investigations should follow the scientific method. (10)*

> *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. (5)*

Many of the apprentices worked on experimental projects, where variables were controlled and manipulated in order to test hypotheses. For example, apprentice 8 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, students who participated in such experimental work often indicated that their apprenticeship experiences reinforced their views of a single scientific method. What is surprising is that even students who participated in observational studies typically adhered to the misconception of a single scientific method. For example apprentice 3 worked in a germ plasm repository collecting observational data on the growth and development of cloned plants. Despite the fact that she participated for 8 weeks in non-experimental scientific work, she believed that the only valid scientific methodology was experimentation:

> Researcher:
>
> *Do all scientific investigations follow the scientific method?*

Apprentice:

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 or some reason. But that wouldn't really be considered a scientific experiment, 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?

Apprentice:

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. (3)

Another apprentice, whose description of the scientific method included testing hypotheses and controlling variables, stated that her apprenticeship reinforced her understanding of a single scientific method:

(My apprenticeship) is where I became, like, really familiar with the scientific method. I probably still can't list all the steps, because that's not what we were doing. But, we were using the scientific method actively and so that's why I think I have an idea of what it is. Because, I know that you always aim to follow the scientific method. (2)

Amazingly, this apprentice's work did not involve experimentation. Rather, she was participating in a correlational study that sought to link physical characteristics of garter snakes to their gravity.

While most apprentices identified valid science with experimentation, a few recognized that there are many ways to do science. None of these apprentices associated this knowledge with their apprenticeship experience, however.

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. (7)

Not all scientific investigations follow the exact same method. Some do not lend themselves well to experimentation...there is no one set scientific method. (9)

The scientific method can mean one of two things. First, there is the six-step process that school children are taught. Second, there is the more fluid method that scientists actually use. (6)

Another aspect of knowledge about scientific inquiry emphasized in the current reforms is the notion that science involves testing ideas. The understanding that doing science involves testing ideas was evident in all of the apprentices' responses to the pre- and posttest questionnaires and interviews. Many of these were in response to the last item on the questionnaire that asked respondents to design an investigation.

Researcher:

What do you mean by "experiment" on the last question?

Apprentice:

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. (2)

I would first develop a hypothesis...after this, I would observe each one of the bird houses and compare its characteristics to my hypothesis. I would then re-evaluate my hypothesis as needed. (7)

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. (8)

It is important to note that the apprentices' pretest responses were no more complete or elaborate than their posttest responses regarding their understandings of testing ideas. Thus, the apprentices apparently learned what they knew about this aspect of scientific inquiry prior to their entering the apprenticeship program.

None of the apprentices indicated that it would be important to consider existing knowledge when designing their birdhouse investigations (question 8). This is surprising, because most of the mentors required their apprentices to review existing literature prior to beginning their apprenticeship work. Additionally, 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. Finally, the apprentices' responses to the questionnaires and interviews did not allow for assessment of the concept that scientists use logic, and higher-order thinking in their investigations.

In summary, 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 enhanced by their work with scientists. This finding is not unexpected. 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 logic, higher-order thinking, and current knowledge; and investigations may lead to more questions). In fact, the apprenticeship appeared to have reinforced inaccurate understandings of these ideas in some cases.

Impacts on Conceptions of Scientific Inquiry

Most apprentices' views of scientific inquiry appeared to stem from science classes, reading science books, and from parents who happened to be scientists. The misconception that scientists use a single scientific method appeared to originate from middle school and high school science classes and school textbooks.

Apprentice:

Scientific method is a process used to find answers to questions and experimentation. And we have six basic steps to find your answer. There is forming an hypothesis, researching and experimenting, ah...collecting data. analyzing data...um

Researcher:

Where did you hear that there were six steps?

Apprentice:

Oh, science books always have them. I have seen books that have six. I have seen books that have seven. They have different ones, but basically the same thing. (10)

I did not answer the questionnaire from my apprenticeship, so much as from the science classes I have taken. (5)

From what I read in school about science, I always had the impression that science is a very official sort of business, very much like following a checklist of the scientific method. (2)

One apprentice noted a difference between what is taught in school science and real science.

First there is a six-step process that school children are taught. Second, there is the more fluid, but similar method that scientists actually use. (6)

One apprentice who articulated a more accurate view of conducting scientific investigations appeared to gain his knowledge from his parent. When asked, Is it good to follow all the steps? Apprentice 7 responded,

Well it is a good idea, but 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.

Although Apprentice 2 connected her ideas of listing the steps of the scientific method to school science classes, she appeared on the verge of changing her views. Her summer field experience of catching snakes may have influenced her thinking about the ways some scientists gather and interpret data.

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.*

In most cases, apprentices stated that answers to the questionnaire did not reflect discussions during the summer. Instead, they stated that talk during the apprenticeship centered mainly on immediate tasks.

We mostly just talked about planning experiments. (5)

On the positive side, some apprentices did gain an understanding of the unpredictability of laboratory life.

Before, I thought that experimentation was done in kinda rigid manner. You do this at ten oclock in the morning. And then you do something else at 1:30 in the afternoon. But when I was working this summer, my day always changed, it was never the same. In school we actually followed the scientific method.. What we think is going to happen...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. (7)

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 enhanced by their work with scientists. This finding is not unexpected. 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 logic, higher-order thinking, and current knowledge; and investigations may lead to more questions.). In fact, the apprenticeship may have reinforced inaccurate understandings in some cases. Almost all apprentices appeared entrenched in their prior belief in a single scientific method, and many apprentices credited their apprenticeships as supporting this belief. At most, a few apprenticeships appeared to stir up the beginnings of change in thinking that scientists use diverse methods.

Mentors

Mentors were responsible for providing the research framework for the apprenticeships and guidance to the apprentices. When asked what they believed the apprentices learned about science, the mentors provided many responses, mostly pertaining to aspects of inquiry.

> *He 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. (Mentor 10)*

> *(Apprentice 1) 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. (Mentor 1)*

Mentors made far fewer comments about the apprentices learning aspects of the nature of science. Only one mentor focused on multiple aspects of the nature of scientific knowledge, including tentativeness and objectivity.

> *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.*
> *(Mentor 2)*

Additional comments focused on the impact of society on science and the culture of scientific research.

It is also important for them to understand how research is impacted by societal needs....For example, with our research there is underlying societal importance. (Mentor 1)

I think she experienced the dynamics of how a research group works together. I think she did not know the human element of science. (Mentor 6)

When asked whether they explicitly taught their apprentices about science, the mentors stressed that the way to learn about science is to do science. They also stressed that this was the way scientists 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 of flounder. (Mentor 7)

You learn about science from participating, she learned science for herself. (Mentor 6)

Meetings between mentors and apprentices focused on problem solving related to the projects, and little time was spent on explicitly discussing general attributes of science.

We spent a lot of time explaining the basics needed to complete the projects. (Mentor 3)

Overall, the mentors stressed the importance of the apprentices learning to do science and, as a result of this process, developing knowledge about aspects of inquiry. The mentors perceived that knowledge of inquiry and the nature of science is developed through participation in research. The mentors spent the majority of their time with the apprentices addressing problems with experimental design, and did not seek to explicitly instruct the apprentices in other aspects of science not directly related to the projects.

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.

Discussion and Implications

An adequate understanding of scientific inquiry and the nature of science is a perennial instructional objective of science education. This investigation assessed the effects of an authentic science experience on secondary students' knowledge. The influence of the experience will be described in terms of data collected from research mentors and students. Prior to any discussion of individual perspectives it is important to note that no changes in conceptions were noted in students' conceptions from pre to posttest.

According to the mentor scientists, students were exposed to a full range of scientific investigation experiences. In particular, students were engaged in the development of research methods, data collection, and data interpretation. In general, however, students were not given the opportunity to develop research questions for these investigations. Further, it was assumed by the scientist mentors that students would come to understand science by doing science. This is not surprising, as it is generally assumed that students will learn how to do science as well as learn about science by doing science. In short, it was believed that implicit instruction on these topics would accomplish the desired educational objectives. Unfortunately, students exhibited no changes with few exceptions, in either their understanding of the nature of science or their understanding of scientific inquiry.

With respect to the nature of science, students believed (on both pre and posttests) that scientific knowledge is tentative, based on empirical evidence, and involves creativity and subjectivity. However, these beliefs tended to be superficial, as students ascribed tentativeness to the lack of information and they did not exhibit an in-depth understanding that it is possible for different interpretations of the same data to be valid. Furthermore, students still possessed the misunderstanding that theories eventually turn into laws with more evidence and there was still some misunderstanding about the role of creativity in the analysis of data.

With respect to scientific inquiry, students clearly exhibited the ability to do inquiry, but they also exhibited a strong belief in a single scientific method. Again, there was virtually no change in students' views from pre to posttest. Overall, students' understandings of the nature of science and scientific inquiry did not change. It is especially important to note that the sample of students for this investigation were not representative of the population of secondary students. Students involved in the ASE program are recognized as high ability science students by any criterion. Still, the lack of any change in views clearly indicates the lack of any discernible influence of the program.

Unfortunately, the results of this investigation do not support the intuitive assumption that students will learn about science simply by doing science. Although there is virtually no research to support this assumption, science educators have assumed that students will learn about scientific inquiry and the nature of science simply by doing science. It is quite clear, and substantiated here, that students only learn how to do science, by doing science. Indeed, even this claim must be qualified, as the typical experience is one in which students are provided with questions and, at best, develop an approach to answer the question. The result, as was true in this investigation, is only support for the view that a single scientific method exists. Although this was not the intent of the scientist mentors, students were actually only relegated responsibility for the more menial aspects of scientific inquiry. In effect, they were technicians attempting to answer a question that was already posed and focused. It is not surprising that students' views about the existence of a singular scientific method were reinforced.

With virtually no exceptions, the scientist mentors believed students would learn about science by doing science. Learning about a way of knowing requires reflection on one's actions, not just doing (Bell, Lederman, & Abd-El-Khalick, 1998; Lederman, 1995). As would be expected, students did not learn much about what they had done, they only learned how to perform certain physical skills. How much more data will it take for the science education community to accept that students should not be expected to master what they have not been given an opportunity to learn?

This investigation represents a direct test of the assumption that experience with an authentic scientific experience will translate to increased knowledge about science and scientific inquiry. The results are not surprising and further emphasize the importance of systematic reflection upon one's actions. It is not enough to include such experiences within teacher education programs and undergraduate science experiences. Experiences in authentic science are necessary, but not sufficient. Teacher educators will need to provide opportunities for preservice teachers to explicitly reflect on their actions in such a manner that the nature of science and scientific inquiry are brought to the forefront (Abd-El-Khalick, Bell, & Lederman, 1998). Students do not learn about the nature of science and scientific inquiry by osmosis, as one mentor scientist stated, they learn those ideas and skills that are explicitly addressed. When students only do science, it is the doing, and only the doing, that is explicitly addressed and learned. Teacher education programs should require that all preservice teachers participate in authentic scientific inquiries as well as participate in courses or experiences that explicitly debrief these experiences in terms of the nature of science and scientific inquiry.

Assuming the aforementioned is addressed, our task is not complete. Teachers will then need to develop those skills necessary to translate and communicate the knowledge they have to K-12 students. This translation will need to be both concrete and useable. An effort to develop K-12 teachers' pedagogical content knowledge (PCK) for nature of science and scientific inquiry is needed. The development of this PCK will not occur through osmosis. It will need to be developed and systematically addressed through explicit and context-based science instruction.

References

Abd-El-Khalick, F., Bell, R.L., & Lederman, N.G. (1998). The nature of science and instructional practice: Making the unnatural natural. Science Education, 82, 417-436.

Abd-El-Khalick, F. & Lederman, N.G. (1998, April). Improving science teachers' conceptions of the nature of science: A critical review of the literature. Paper presented at the annual meeting of the National Association for Research in Science Teaching, San Diego, CA.

Aikenhead, G. (1973). The measurement of high school students' knowledge about science and scientists. Science Education, 12(4), 52-549.

American Association for the Advancement of Science (1989). Project 2061: Science for all Americans. Washington, DC: Author.

Bady, R.A. (1979). Students' understanding of the logic of hypothesis testing. Journal of Research in Science Teaching, 16, 61-65.

Bell, R.L., Abd-El-Khalick, F., & Lederman, N.G. (1998). Implicit versus explicit nature of science instruction: An explicit response to Palmquist and Finley. Journal of Research in Science Teaching, 35, 1057-1061.

Bell, R.L., & Blair, L.M. (1997). [Characterization of 1997 apprenticeships]. Unpublished raw data.

Broadhurst, N.A. (1970). A study of selected learning outcomes of graduating high school students in South Australian schools. Science Education, 54, 17-21.

Cooley, W.W. & Bassett, R.D. (1961). Evaluation and follow-up study of a summer science and mathematics program for talented secondary school students. Science Education, 45, 209-216.

Gallagher, J. J. (1991). Perspective and practicing secondary school science teachers' knowledge and beliefs about the philosophy of science. Science Education, 75, 121-134.

Hodson, D. (1993). Re-thinking old ways: Towards a more critical approach to practical work in school science. Studies in Science Education, 22, 85-15.

Lederman, N.G., & O'Malley, M. (1990). Students' perceptions of tentativeness in science: Development, use, and sources of change. Science Education, 74, 225-22.

Mackay, L.D. (1971). Development of understanding about the nature of science. Journal of Research in Science Teaching, 8, 57-66.

Miller, P.E. (1963). A comparison of the abilities of secondary teachers and students of biology to understand science. Iowa Academy of Science, 70, 80-83.

National Research Council. (1996). National science education standards. Washington, DC: National Academic Press.

Ritchie, S.M. & Rigano, D.L. (1996). Laboratory apprenticeship through a student research project. Journal of Research in Science Teaching, 33, 799-815.

Rubba, P., Horner, J., & Smith, J.M. (1981). A study of two misconceptins about the nature of science among junior high school students. School Science and Mathematics, 81, 221-226.

Schmidt, D.J. (1967). Test on understanding science: A comparison among school groups. Journal of Research in Science Teaching, 5, 365-366.

Smith, M.U., Lederman, N.G., Bell, R.L., McComas, W,F. & Clough, M.P. (1997). How great is the disagreement of the nature of science: A response to Alters. Journal of Research in Science Teaching, 34, 1001-1003.

Tobin, K. & Gallagher, J.J. (1987). What happens in high school classrooms? Journal of Curriculum Studies, 19, 549-510.

Welch, W.W. (1979). Twenty years of science curriculum developments: A look back. In D.C. Berliner (Ed.), Review of research in education (vol. 7, pp. 282-306). Washington DC: American Educational Research Association.

Appendix A
Sample Apprenticeship Profiles

Sample Apprenticeship Profile 1

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). In order 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 1

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-utilizing microbes. The apprentice conducted experiments on degradation rates utilizing 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 bi-weekly 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.

Appendix B
Apprentice Questionnaires
Nature of Science 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 while others believe that it is shrinking; still others believed that the universe is in a static state without any expansion or

shrinkage. How were these different conclusions possible if the astronomers if all of these scientists 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 bird-houses 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 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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