

Understanding The Impact of an Apprenticeship-Based Scientific Research Program on High School Students' Understanding of Scientific Inquiry

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Abstract The purpose of this study was to understand the impact of an apprenticeship program on high school students' understanding of the nature of scientific inquiry. Data related to seventeen students' understanding of science and scientific inquiry were collected through open-ended questionnaires. Findings suggest that although engagement in authentic scientific research helped the participants to develop competency in experimentation methods it had limited impact on participants' learning of the implicit aspects of scientific inquiry and NOS. Discussion focuses on the importance of making the implicit assumptions of science explicit to the students in such authentic scientific inquiry settings through structured curriculum.

Keywords Authentic scientific inquiry · High school · Nature of science

Introduction

Acquisition of scientific inquiry skills and an adequate understanding of the nature of science [NOS] are the two prominent goals of science education reform. The *National Science Education Standards* (National Research Council [NRC] 1996) define inquiry as “the diverse ways in which

scientists study the natural world and propose explanations based on the evidence derived from their work” (p. 23). The five hallmarks of inquiry-based learning experiences include: Learners engage in development of scientifically-oriented questions; learners give priority to evidence, which allows them to develop and evaluate explanations that address scientifically-oriented questions; learners formulate explanations from evidence; learners evaluate their explanations in light of alternative explanations, particularly those reflecting scientific understanding; and learners communicate and justify their proposed explanations. The most agreed upon definition of NOS emphasizes the epistemological values, assumptions of science as well as its connections with social, individual and cultural values and biases (Lederman and Abd-El-Khalick 1998; Loving 1997; McComas 1996; Ryan and Aikenhead 1992; Schwartz et al. 2002). The aspects of NOS emphasized in science education literature include that scientific knowledge is tentative, it is subject to change based on new observations, evidence and reinterpretations of existing observations and evidence, it is based on empirical evidence: is derived from observations of the natural world, it is the product of human's imaginations and critical thinking, it is subjective in that it is influenced by current theories and that personal values and experiences influence how scientists perform science. Other aspects of NOS emphasized in science education literature are, scientific knowledge is influenced by the society and culture in which it is practiced, theories and laws are two different kinds of knowledge and that there is a difference between observation and inference (Schwartz et al. 2004). Although scientific inquiry and NOS are often discussed separately, it is hard to separate one from the other (Schwartz et al. 2004). It is believed that students or teachers will not be able to effectively participate in scientific inquiry if they do not understand the

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explicit and implicit assumptions and values of science. Without understanding the assumptions and values of science students are likely to construct an image of scientific inquiry that is limited to experimentation. Similarly, the naïve views of NOS held both by teachers and students are attributed in part to their lack of experiences in conducting scientific inquiry (Brown and Melear 2006; Eick 2000; Lederman 2007; Schwartz and Crawford 2003; Gallagher 1991).

In spite of the emphasis placed on inquiry-based learning and an adequate understanding of NOS in science education reform documents such as Benchmarks for Scientific Literacy (American Association for Advancement of Science [AAAS] 1993) and NSES (NRC 1996) and contemporary science education literature (Abrams et al. 2007; Lederman 2007), research reports (NRC 2000; National Academies of Sciences [NAS] 2005) maintain that instruction in most American k-12 classrooms fails to promote students' acquisition of such understandings, knowledge and skills.

For instance, a recent report by the NAS (2005) revealed that high school science laboratories fail to engage students in inquiry-based learning. The report stated that although science laboratories have been a part of school science curricula for a long time, "a clear articulation of their role in student learning remains elusive" (NAS 2005, p. 13). Science education literature also reports similar findings. For instance, many research findings suggest that activity without understanding is a common feature of science laboratories in many public school classrooms (Hofstein and Lunetta 2004; Wallace and Kang 2004; Roth and Garnier 2007; Windschitl et al. 2008). As currently enacted, many laboratories fail to provide a context for students to understand the explicit and implicit assumptions of science such as the epistemologies of science and the nature of scientific knowledge (Chinn and Hmelo 2002; Chinn and Malhotra 2002; Germann et al. 1996). In other words, laboratories focus only on demonstrations and experimentation aspects of the scientific inquiry, and fail to emphasize the theory development, socially negotiated nature of scientific knowledge and an understanding about the influence of social biases on the products of science (Chinn and Malhotra 2002; Longino 1990; Schwartz and Lederman 2006; Windschitl et al. 2008). This exclusive emphasis on the experimentation fails to provide a context for high school students to understand how the scientific knowledge gets generated and validated.

This challenge is hard to overcome in traditional classroom settings due to teachers' naïve views of scientific inquiry (Eick 2000), their limited experiences with and knowledge of scientific inquiry (Brown and Melear 2006), the time, curriculum priorities and the pressures of test-driven accountability policies (Aydeniz 2007; Abrams et al. 2007; Blanchard et al. 2009). Therefore, science

educators worldwide are working to create contexts conducive to the promotion of such learning goals beyond the classroom. For instance, teaching high school students about the processes of scientific inquiry by placing them in authentic contexts is increasingly becoming popular among science educators (Hsu and Roth 2009; Richmond and Kurth 1999; Roth and Roychoudhury 1993; Sadler and Burgin 2009; Schwartz et al. 2004; Stake and Mares 2001, 2005; Templin et al. 1999). Although these programs are becoming popular and define the nature of most university and k-12 partnerships, we know little about how engagement in such learning experiences contributes to high school students' understandings of the epistemologies of science, understandings and knowledge of scientific inquiry, and their aspirations to become scientists.

The purpose of the study was to explore how engagement in inquiry-based learning experiences in an authentic scientific research setting contributes to a group of high school students' understanding of the nature of science and scientific inquiry.

Review of Literature

Providing inquiry-based learning experiences for high school students in authentic scientific research settings have become increasingly popular in recent years (Bleicher 1996; Bell et al. 2003; Charney et al. 2007; Barab and Hay 2001; Lee and Songer 2003; Ritchie and Rigano 1996; Stake and Mares 2005). For a recent and comprehensive review of such programs see Sadler et al. 2010. Sadler et al.'s (2010) review of such programs reveal that these programs have a positive influence on students' understanding of NOS, interest in pursuing science related careers, self confidence in performing science and intellectual development. However, given the limited number of participants in the studies that Sadler et al. (2010) reviewed and the diversity of participants (i.e., high school, college students and teachers), and the diversity in the length of programs that serve as a context for past studies, more research needs to be done to develop a better understanding of the limitations and the potential of authentic scientific research experiences offered to high school students. Out of the 20 studies that were designed for high school students and reviewed by Sadler et al., only in two studies high school students engaged in authentic scientific inquiry for an academic semester or longer. The total number of the participants in these two studies is nine. In addition, not all of these studies explored the impact of these experiences on students' understanding of the nature of science and scientific inquiry. For instance, only two studies (Bell et al. 2003; Charney et al. 2007) focused on students' understanding of the nature of science. The total

number of participants in these studies combined was 40. This limited number of participants call for the need to further investigate the influence of authentic scientific experiences on high school students' understanding of the nature of science and scientific inquiry.

Brown et al. (1989) define authentic activities as, “ordinary practices of the culture” through which the purposes and meaning of their actions are constructed, negotiated and refined by present and past members (p. 34). The authentic setting in the context of this study refers to the university science laboratories or national laboratory where expert scientists conduct their investigations, collect and analyze their data, and form scientific theories (Latour and Woolgar 1986; Roth 1995). Authentic activities associated with authentic scientific inquiry include “designing complex procedures, controlling for nonobvious confounds, planning multiple measures of multiple variables, using techniques to avoid perceptual and other biases, reasoning extensively about possible experimental error, and coordinating results from multiple studies that may be in conflict with each other” (Chinn and Hmelo 2002, p. 2) and developing defensible, evidence-based explanations.

The inquiry-based learning experiences provided to high school students in authentic settings are designed based on an apprenticeship model (Sadler et al. 2010). Within this apprenticeship model, high school students are placed in a science laboratory under the supervision of a graduate student or a professor to engage in an ongoing research project or guided to start a new scientific research project (Sadler et al. 2010). One of the assumptions of such programs is that novices (i.e., high school students) will enhance their understandings, knowledge and skills in relation to scientific inquiry through participation in rituals of the scientific culture in an organized fashion under the supervision of a master scientist (Lave and Wenger 1991; Rogoff 1990). Roth (1995) points out, “Apprenticeship offers direct exposure to the realities of the actual workplace and, in this, facilitates the emergence of skills, problem solving techniques, knowledge and language of practitioners in the context of everyday out of school practice” (as cited in Hsu et al. 2009, p. 482). One of the justifications for this argument is based on the situated accounts of learning which asserts that knowledge is highly contextualized and is best learned in settings in which it occurs (Brown et al. 1989; Lave and Wenger 1991). It is also believed that when novices learn science on the shoulders of expert scientists they are more likely to acquire adequate knowledge and skills about the process of scientific inquiry and develop adequate understanding of NOS. Finally, it is believed that when high school students conduct research in science laboratories under the guidance of a scientist, they will develop aspirations to become scientists. However, given the limited number of

participants studied so far, we cannot make grand conclusions about the influence of such programs on students' learning and aspirations to become scientists Sadler and Burgin (2009) state, “while reports cast a positive light on these programs, the empirical support for these claims is somewhat tenuous” (p. 3). Therefore, more empirical inquiries are needed to measure the influence of these apprenticeship programs on students' understanding of the nature of science and scientific inquiry.

Significance of the Study

We designed this study is to understand how engagement in scientific inquiry experiences in authentic settings influence high school students' understanding of the nature of scientific inquiry and nature of science. We believe the results of this study will enhance our understanding of current practices, guide us in understanding how to best structure these experiences to enhance students' personal engagement with science in a way that is consistent with epistemologies of science and practices of scientists. In addition, we believe this study is important because such an understanding can serve as a resource for scientists who have limited knowledge of effective pedagogies to facilitate students' learning about the process and products of science. The following question guided this inquiry.

How does an authentic scientific research experience over a sustained period of time (i.e., two academic semesters) impact high school students' understanding of the nature of science and scientific inquiry?

Methods

This study was conducted through a qualitative case study methodology (Merriam 1998). Merriam (1998) defines case study as an in-depth investigation of an individual, group or an event with the purpose of uncovering the underlying causes of a problem observed with the individual or the group. Case studies are useful in educational research because most educational phenomena cannot be easily understood by establishing casual relationship between two numbers. In order to gain an in-depth understanding of the important issues such as finding out about the influence of engagement in an authentic scientific research experience over a sustained period of time on high school students' understanding of scientific inquiry and NOS case study methodology proves to be useful. Case study methodology is useful not only because it allow for in-depth analysis of an issue, but it has potential to result in hypotheses development that may be critical to addressing

an educational phenomena as important as students' understanding of scientific inquiry and NOS.

Program Description

This study took place in a suburban high school in a southeastern state in the United States of America. The participants were recruited from Seminole Science Academy (SSA) program (pseudo name). The goal of the program is to enhance high school students' interest in science through participation in authentic scientific research at a research-intensive university or a national science laboratory. The program provides research based, lab driven, field experiences in science, engineering, math, and/or technology fields for the participants.

Lave and Wenger's (1991) legitimate peripheral participation theory guided the design of this program. Lave and Wenger (1991) characterize learning as "legitimate peripheral participation in communities of practice" (p. 30). Two terms, legitimate and peripheral, are central to this apprenticeship-based model of learning. The terms legitimate and peripheral mean that there are multiple levels of participation in the practices of a community. Those who can fully and effectively participate in the practices of a community are considered to be legitimate participants. Those who are not able to fully participate in the practices of a community are considered as peripheral participants. Peripheral participants are less engaged in the practices of community, and have a limited understanding of the values of the community in which they are a part.

In our study we conceptualize the community of practice as a group of scientists who are conducting authentic scientific research at a research-intensive university or a national laboratory, with a group of high school students trying to achieve legitimacy by participating in authentic scientific inquiry. These scientists engage in basic/professional research, employing epistemologies of science, the norm and values of scientific community. Novice scientists are high school students, who are intentional learners; supported by their mentor teachers, school administrators and university mentors to engage in the activities of expert scientists.

When describing the path to the legitimacy, Lave and Wenger (1991) state: "learner inevitably is to participate in communities of practitioners and that the mastery of knowledge and skill requires newcomers to move toward full participation in the sociocultural practices of a community" (p. 29). Thus, in this apprenticeship model, novices are introduced into the community of expert scientists through discourse in the context of relevant tasks. In the context of this study, we consider someone to be a legitimate participant if he/she engages in everyday professional activities practiced by expert scientists using the norms of

scientific community, holds adequate understanding of NOS and scientific inquiry, and is recognized by self and meaningful others (i.e., expert scientists) as capable of doing science. Thus, the expected learning outcomes for the students included: an adequate understanding of the nature of science, scientific inquiry and aspirations to become scientists. The university/lab mentors (i.e., scientists) were conscious of the goals of the program (i.e., helping students to develop adequate understanding of the scientific inquiry, experience the process of scientific inquiry and develop interest in science and related careers) as they all went through the orientation and volunteered to mentor these academically gifted novice scientists. In addition, we interacted with these scientist mentors and engaged in conversations with them about students' experiences in a frequent manner. The content of our conversations suggest that the scientist mentors are aware of the goals of the program.

Selection of Participants

We selected the participants into the program based on teacher recommendations that addressed students' enthusiasm for science, responsibility, initiative and ability to work independently. Students are required to be on track to complete three core science courses (chemistry, biology, and physics) and two science electives, one at the advanced placement (AP) level. We select the participants for the program either during the spring semester of their sophomore or junior year.

Students participating in research at the university, choose a project from descriptions of ongoing projects provided by potential university/national laboratory faculty mentors. Students register for one credit hour per term; however, the credit hour assigned does not limit the number of hours a student may work in the laboratory. The university faculty mentor, the teacher mentor, and the students determine this arrangement. Students also receive one high school credit for each semester they participate in these research experiences.

Students conducting research at the national laboratory submit an application describing their qualifications and interests and are selected by a scientist mentor accordingly. At the beginning of each project, the students meet with the scientist mentor to outline the project and expectations. While it is understood that the instruction will involve participation of graduate students and post-doctoral associates, the scientist mentor is directly responsible for working with the students and monitoring their progress.

Although the university/national lab mentors (i.e., scientists) were conscious of the goals of the program, different mentors and lab contexts provided different experiences to the participants. For instance, while all

students participated in the “doing of science”, not all lab contexts engaged students in a discourse designed to explicitly nurture participants’ understanding of NOS and scientific inquiry. Moreover, while the majority of mentors guided the students through the entire scientific process, some of them were more hands-off and encouraged students’ autonomy. The majority of mentors welcomed the students into an existing research project, debriefed the participants about the purpose of the study, trained them about the use of instruments that they used to collect and analyze data, and guided the students to analyze and interpret data to draw conclusions. A statement such as “My mentor and the graduate students at the lab explained the processes and the background. Then, the graduate students showed me the techniques needed, step-by-step and explained the reasons why we were doing each step” was common across all participants. Although the majority of students did not form a research question, they engaged in various activities that the scientists themselves do following the norms of expert scientific community. For instance, one student said, “I did a little bit of everything in the project ranging from designing reactions, purification, collecting, analyzing data and writing conclusions.” Some students provided specific answers about their experiences in the lab. To indicate the diversity in the activities that the student engaged in we provide the following two excerpts as examples of students’ learning experiences in these authentic settings (these students’ research questions were not revealed because of confidentiality).

Student A: The graduate students took me through the procedures and showed me how to use the equipment. We synthesized the monomer and polymer, and then collected data through NMR and GPC techniques and analyzed the data. We also collected data from rheology, which shows viscosity, flow, and viscoelasticity.

Student B: I looked at the curve and my mentor explained how to interpret the curve. I received help from my mentor in interpreting the results, and the protocols to use for RNA and DNA extraction. I looked at my data and thought about whether or not it supported my hypothesis. My graduate student mentor and my faculty mentor both helped me interpret my results.

Student reports reveal that all participants engaged in data collection and analysis, and all of them received some sort of help either from their mentors, the graduate student or both throughout the process. While the student autonomy was encouraged in most cases, the mentors provided guidance and help throughout the process.

After participating in scientific research in an authentic setting, the students present the results of their scientific investigations at a poster session hosted by the SSA. The SSA poster sessions, conducted in December and May of

each year, are billed as “academic pep rallies.” Local officials, University deans and mentors, mentors from the national lab, parents, and community members come to learn about and celebrate the work done by these students. Mentors, community members, local officials, students, and high school teachers interact; focus on the work of these students by listening to their explanations and asking them questions about their projects.

Participants

The participants for this study were 17 high school students, recruited from juniors and seniors who completed their projects for the 2009 school year. Sample consisted of ten males and seven females. Ten participants self-identified themselves as of Asian, six as of White and one as of Hispanic origin. Each participant engaged in the authentic scientific research experience over a period of two academic semesters.

Data Sources

Three types of data were collected in this study: students’ responses to a likert-scale nature of science (NOS) survey (see “Appendix 1”) informed by (Chen 2006), and designed based on the NOS themes emphasized in VNOS (Lederman et al. 2002) (see “Appendix 1”), their responses to the Views of Scientific Inquiry (VOSI) (Schwartz et al. 2008) and their responses to a set of 23 open-ended questions survey (Seminole Science Academy Survey [SSAS]) (see “Appendix 2”) that focused on nature of students’ participation in scientific research. The content of the likert-scale NOS survey is displayed in Table 1.

While nine of the 23 questions in the open-ended survey focus on students’ attitudes towards scientific research, and the structures (i.e., parents socioeconomic status, teacher mentoring) that helped them to gain access to the program, the rest of questions focus on students’ learning about the

Table 1 Content of NOS survey

Statement #	NOS aspect emphasized
1, 2, 3, 4, 18	Understanding of theory formation
1, 2	Understanding of theory formation, alternative explanations
5	Tentative nature of science
6, 7, 8	Creativity and imagination
9, 10	Subjectivity/objectivity
11	Importance of verification in science
12, 13	Multiplicity in methods of inquiry
4, 14, 17	Empirically based nature of science
15, 16	Definition of science

epistemologies of scientific inquiry in the context of their research experiences. These questions were designed in a way to help us understand how engagement in scientific research contributed to their learning about the epistemologies and practices of science. In addition, we used an 18 item, likert scale NOS survey (see “[Appendix 1](#)”) to understand participants’ beliefs about various aspects of NOS. We did not use the open-ended VNOS instrument because we did not want to overwhelm the students as we were already asking them to do too much with the VOSI and the open-ended questionnaire. We acknowledge the limitation of the likert-scale NOS instrument but think that it gave us a proxy of students’ understanding related to various aspects of NOS emphasized in VNOS. Five science educators who study NOS looked at the NOS survey (Chen 2006) and agreed that it emphasized all aspects of NOS in the VNOS instrument (Lederman et al. 2002) with the exception of social and cultural influences on the nature of science.

Data Analysis

Three sets of data were analyzed, students’ responses to a general questionnaire that prompted students to describe the nature of their experiences and experiments, their responses to Views of Scientific Inquiry (VOSI), and a nature of science survey. We analyzed participants’ responses to the questionnaire to characterize the learning discourse (i.e., their experiences in the labs) and report on the types of learning that took place while students were in the laboratories and the level of autonomy that was given to the students. For instance, some of the responses given by the students were categorized based on whether the experience helped the participants to engage in scientific epistemologies or just activities such as simple data collection that has no epistemic value. These data helped us to situate students’ responses related to the nature of scientific inquiry and NOS in a relevant context and interpret their responses accordingly.

Students’ responses to VOSI and general questionnaire ([Appendix 2](#)) were evaluated based on their epistemic value related to various aspects of science by the authors over a sustained period of time. These aspects included the nature of scientific investigations, the role of hypothesis in the process of scientific inquiry, the difference between evidence and data, the difference between observation and experimentation, the nature of theory development, the empirical basis of scientific knowledge, the subjectivity of scientific inquiry, and the social nature of scientific inquiry. Each author independently reviewed data and gave a score of “acceptable response” or “not acceptable response” for each student and each question. Then, the authors collectively reviewed students’ responses, compared their

scoring decisions to come to a consensus about the quality of students’ responses. However, from time to time we encountered responses that did not fit in either of the categories (i.e., acceptable and not acceptable). In that case, authors conducted further analyses and engaged in collective decision making about the validity of the epistemic value of each student’s response to place the student in the closest category. This rigorous process of evaluation was followed in an effort to reduce bias and subjectivity. Finally, we analyzed students’ responses to the NOS survey to assess students’ understanding of various aspects of NOS. Participants’ understanding related to various aspects of NOS were evaluated as being either acceptable or not acceptable. If the participant either strongly agree or just agreed with the statement about a certain aspect of NOS on the survey the answer was considered acceptable, if the participant disagreed or strongly disagreed with the statement, the answer was not considered acceptable ([Appendix 3](#)). Those who expressed a neutral view were also considered not acceptable because we were interested in finding out how the experience in this authentic inquiry setting helped the participants to develop an adequate view about various aspects of NOS. We were not interested in creating student profiles (e.g., naïve, developing, sophisticated) related to their overall understanding of NOS.

For students’ understanding related to each aspect of scientific inquiry and NOS, we developed assertions, evaluated the validity of these assertions through the process of peer review and repeated readings of the raw data. The final assertions were reached through triangulation of data and consensus among the authors. Assertions about student learning in relation to scientific inquiry was drawn based on students’ responses to a survey on students’ experiences in the program (see “[Appendix 2](#)”), Views of Scientific Inquiry (VOSI) instrument (Schwartz et al. 2008) and the nature of science survey (see “[Appendix 1](#)”). Each assertion was supported by quotations from students’ responses to the likert scale NOS survey, VOSI or both. In order to maintain confidentiality we did not report the research questions that the participants worked on while providing supporting quotes from participants’ responses.

Quality Criteria

Prolonged engagement with participants and the context of a study is a desirable goal when conducting a qualitative study to ensure quality criteria (Guba and Lincoln 1989). Two of the authors were actively engaged in the recruitment, placement and monitoring of students’ research experiences. This prolonged engagement took place through weekly meetings with the program participants in the science academy course. The mentor teachers who are the coauthors in this paper inquired about students’

experiences in the laboratories, listened to their questions and concerns. They attended regular meetings with the faculty at the university, organized and supervised two poster sessions which allowed the participants to share the reports of their research with their teachers, mentors, students and general public. This active and constant form of communication provided invaluable insights into the experiences, motivation, and learning of the participants pertinent to the focus of this study. More important, coauthors' understandings of students' experiences in the science laboratories enabled us to make better judgments about students' responses to the written assessments.

Results

We report findings related to high school students' understanding of the nature of scientific inquiry and science after participating in an authentic scientific research program over a sustained period of time (two academic semesters). The results are reported thematically.

Nature of Student Learning: Focus on Knowledge and Skills About Methods of Doing Science

Helping students to acquire knowledge and skills to perform scientific inquiry was one of the explicit goals of the SSA. Therefore, it is important to understand the influence of the program on participants' knowledge and skills to do science.

Findings revealed that the majority of the participants (15/17), learned to use specific instruments for conducting their research, including data collection and analysis. For instance, one student said:

I learned the techniques used in the polymer chemistry lab, including synthesis of monomer and polymer, the processes in which chemists verify the solutions, and the data analysis involved. I also learned the details of atom transfer radical polymerization involving the steps of initiation, propagation, chain transfer, and termination.

Another student said, "I learned molecular techniques like RNA and DNA extraction, how to use RT-PCR machine." One student expressed his amazement by the quality of techniques he learned by saying, "I learned many standard laboratory techniques that are used by biochemists and molecular biologists around the world. The methodologies and laboratory protocols I learned were more advanced than I had expected. Phenotypic expressions of cells after transfection."

As these excerpts indicate, participants learned very advanced data collection and analysis techniques that they

would not have had access to in traditional school science laboratories. Developing knowledge of specific data collection and analysis techniques may help novices to feel confident about their abilities to do science and thus to pursue advanced opportunities in scientific research beyond high school.

Participants' Understanding of the Nature of Scientific Inquiry

The specific learning outcomes that were assessed in this domain include, students' understanding of the nature of scientific investigations, the difference between evidence and data, the difference between observations and experimentation, nature of data analysis, the singularity of the scientific method, the process of theory formation, the tentative nature of scientific knowledge and the role of consensus building during the process of knowledge generation.

Difference Between Observations and Experiments

The majority of participants (15/17) showed an adequate understanding of the difference between an experiment and an observation. Participants' level of understanding was measured based on their evaluation of the bird scenario question on the VOSI. We considered a statement such as, "No, this is not an experiment. There is no control or replications, thus it is not an experiment" as reflecting an adequate understanding, and a statement such as "Yes, because they are trying to find why there are these differences between such like animals" as reflecting a naive understanding of scientific experimentation. The participants were also asked to evaluate whether the person's observations and the conclusions in the bird scenario were scientific or not.

The results showed that only two students out of the 17 who participated in this study were not able to make a distinction between a scientific investigation and experimentation. One of the students who did not consider the observation as scientific stated, "No, this is not an investigation. This is only a study. For his hypothesis to be trustworthy he would have to design an experiment with controls. This is a logical conclusion, but it cannot be called scientific." It is obvious that this student emphasized the empirical nature of scientific investigations but did not consider observational data as being part of the scientific process. A statement such as, "Yes, although he did not follow the scientific method, he observed his environment and found a correlation that may explain a problem that he found", was considered to reflect an acceptable level of understanding about the nature of scientific investigations. This was considered as an acceptable answer because the

student did not limit the scientific inquiry to the scientific experimentation. Limiting scientific investigations to experimentation reflects a naïve understanding of the nature of scientific investigations. This is because scientific experimentation constitutes only one aspect of the process of the scientific knowledge generation.

Difference Between Data and Evidence

Understanding the difference between data and evidence is an important aspect of a sophisticated NOS understanding. The findings revealed that only 11 out of 17 participants were able to emphasize the difference between data and evidence. A statement such as, “Data means evidence to confirm or not confirm a hypothesis”, or “They are similar because they’re both information” was considered to reflect an inaccurate understanding about the difference between data and evidence. A statement such as, “They are different in that data does not have to prove anything while evidence is usually used in support of an idea” was considered to reflect an acceptable understanding about the difference between evidence and data. As evidenced in students’ responses, a significant number of the participants (6/17) were not able to develop sophisticated understanding about the difference between evidence and data after engaging in scientific experiments over two academic semesters.

Singularity or Multiplicity of Scientific Inquiry Methods

One of the misconceptions that both the students and teachers of science hold about the nature of scientific inquiry is that scientists use one single universal scientific method to do science (Abd-El-Khalick and Lederman 2000; McComas 1996; Windschitl et al. 2008).

Findings suggest that all participants viewed science as a way of thinking about the world around us. The majority of participants (13/17) stated that scientists use multiple methods to solve a problem. However, they all indicated that each alternative method must be consistent with the scientific method. While some students limited the process of scientific inquiry to the scientific method, starting with observations and ending with data interpretations and conclusions, others expressed more sophisticated understandings about the process of scientific inquiry. For instance, while one student said, “I learned that scientists do background research, form a hypothesis, observe, collect data, analyze data, draw conclusions, and test those conclusions”, Another student who also viewed science only through the lens of the scientific method said, “I learned the processes of scientific research, first beginning with a goal and finally, being able to interpret the results.” While the first student characterized science as the testing

of a hypothesis through the scientific method, the latter emphasized the interpretation of the results related to a problem. Yet, both students had a naïve understanding in this domain because they did not acknowledge that scientific inquiry is a messy cyclic process and not a step-by-step rigid process (Windschitl et al. 2008).

Only few students (4) were able to view the process of scientific inquiry through a sophisticated perspective. The following statement is an example of a student who held a sophisticated perspective in this domain. The student said, “There is no one route to true scientific investigation due to the fact that people perceive and examine things differently. Paralleling this is the thought that any method used to make conjectures about the world can be considered scientific.” This particular student believed that scientists use multiple methods to do science and emphasized the diverse ways in which people perceive, examine and analyze things as his justification. Another student, who emphasized the messy side of scientific inquiry said, “I learned that much of our research is based on trial and error. You can’t start off in the dark, but you don’t have to know it all. I learned this by watching grad students’ progress in their projects.”

Although the views of scientific inquiry expressed by the majority of the participants acknowledge the diverse methods in which scientists engage in their work, participation in these authentic scientific experiences led a sizable number of students to reinforce their existing naïve beliefs that the scientific method is the only method that the scientists use to generate knowledge. It is our interpretation that the participants held this naïve view about the process of science even after doing science themselves for two semesters because most scientists use the language of the scientific method in their laboratories, even though how they perform scientific inquiry does not always follow the step-by-step procedures suggested by the scientific method.

Role of Hypothesis Formation in the Process of Scientific Investigations

Findings suggest that while almost all students (16/17) held sophisticated views about the process of hypothesis formation, the majority of them (12/17) held naïve views about the role of hypothesis formation in the process of scientific inquiry. The participants who held a naïve view stated that scientists must have a hypothesis before they can study a problem. They claimed that without a hypothesis the process would not be considered scientific because it would have no purpose. One example of such statement is, “Because the whole point of doing an experiment is to get information about what you thought in the beginning.” Another student who had similar understanding stated, “If you aren’t trying to prove something

you can't really prove anything about it." Another student with a similar understanding stated that, "They [scientists] must have good reasons or support to perform an experiment. Before the collection, they must already predict what will happen or have a hypothesis" This view is problematic in the sense that it may lead students to use confirmatory bias method (Dunbar 2001) in their treatment of data during the process of identifying evidence to support a hypothesis. This is problematic because sometimes data that is not related to the proposed hypothesis can lead to new understandings. In fact, the participants further reinforced this understanding when we analyzed their responses related to scientists' treatment of unexpected results.

Only five students' views in this domain were considered acceptable. The students who held an acceptable view though acknowledged that scientists conduct research by forming and following a hypothesis, they were also able to recognize that scientists may come up with hypothesis during the process. The following is one example of such sophisticated understanding. "Scientific investigation does not have to have a particular question to be answered. In many cases, study of a field can create such questions to be answered." However, the majority of participants held a naïve view about the role of hypothesis in the process of scientific inquiry.

Scientists' Treatment of Unexpected Findings

Scientists often use casual reasoning to establish the relationship between a hypothesis and data to identify evidence for theory formation (Dunbar 1997). However, not all experiments produce evidence in support of a proposed hypothesis because of mistakes in their data collection methods or any other reason. Mistakes in science are common and occur for several reasons. Scientists sometimes use the unexpected results that are only distantly related to the proposed hypothesis to make new discoveries or to develop new understanding into the very problem that they are trying to solve (Dunbar 1997). However, the process of making mistakes itself is not as important as identifying and reacting to the mistakes. It was hoped that the participants would be able to develop an understanding into the ways in which expert scientists treat the unexpected findings.

Findings showed that the participants did not develop a sophisticated understanding about the ways in which scientists deal with the unexpected results. Almost all of the participants believed that the scientists use the confirmation bias method in their treatment of unexpected results. In other words, the majority of students (16 out of 17) believed that scientists only use the data that support their hypothesis and ignore data that are not related to their proposed hypothesis. One student who held a naïve view

said, "scientists either engage in a reevaluation of experimental procedures or a repetition of an experiment" when their data fails to support their hypothesis. Another student said, "They try to remove it [errors] by altering methods or they run more tests to get the data they want." The one student who held a relatively sophisticated view said, "They [scientists] embrace it [unexpected result]! Sometimes discoveries are made by accidents or unpredicted results."

The participants' responses indicate that scientists act in three distinct ways in their treatment of unexpected results: re-running the experiments by using the original methods to produce the expected results, modifying or changing the experimental methods to produce the expected results, asking other scientists for an explanation for the inconsistency observed in their data. Only one student believed that scientists use the unexpected results to develop new understandings. The rest of the participants believed scientists engaged in one of these activities mentioned above to produce results that would support their hypotheses.

Process of Theory Formation

Findings suggest that only a small number of the participants (2/17) had an acceptable level of understanding about the ways in which scientists develop theories. The participants emphasized various aspects of theory development. Some emphasized that scientists develop theories starting with making assumptions about the patterns they see in their observations in their studies, others emphasized that scientists verify the results of their experiments through multiple testing. For instance, one participant, who emphasized the role of verification in theory development said, "They [scientists] develop them after much verification and time. They conduct more experiments in different procedures and if they conclude the same thing, it goes on the way to become a theory." Another student said, "Theories are developed from critical thinking and noticing trends." Similarly, other participants emphasized that scientists develop theories by coordinating between their proposed hypothesis and the patterns they see in their data.

The majority of participants (15/17) believed that theories are developed based on empirical evidence. Only two participants pointed out the social aspect of theory development. One of these two students said, "They [scientists] think about it a lot and discuss with many different people before they develop a theory." The majority of participants (12/17) disregarded the possibility of alternative explanations and emphasized that there is only one single scientifically valid explanation of natural phenomenon.

In sum, findings revealed that the participants held naïve understandings about the process of theory development. Only two participants were able to provide a complete

picture of how scientists developed theories. The rest of participants provided an incomplete answer in that they only emphasized one single aspect of theory development (i.e., scientists develop theories based on trends they see in their data or empirical evidence). The majority of participants who engaged in theory development during their internships were not able to elaborate on how scientists developed theories. However, the majority did acknowledge the empirically based nature of scientific theories.

Subjectivity/Objectivity of Scientific Inquiry

Novice scientists' understanding of the subjective nature of science is critical for their competency in science. Students' understanding of the subjective nature of the scientific inquiry was measured through two questions in VOSI. The first question was, "How do scientists decide what and how to investigate?" The second question that measured students' understanding in this domain was, "If several scientists, working independently, ask the same question and follow the same procedures to collect data, will they necessarily come to the same conclusions? Explain why or why not." The majority of the participants were able to acknowledge the subjectivity embedded in the process of knowledge generation in science. The majority of the students believed that scientists investigate things based on what is important to them and to the good of society. "They decide through what is important in the world today and what they are interested in." was a very common answer across all participants. An example of a more elaborate answer is "Scientists decide what to investigate by seeing a problem and wanting to fix that problem. Factors that influence the work of scientists

include their individual interests, the technology available, and the financial resources available to conduct that research." Although all participants acknowledged the subjective nature of scientific inquiry, more than half of the participants indicated their agreement or strong agreement with the statement "scientists can abandon personal biases to make objective observations because they are well trained professionals."

Participants' understanding of the subjective nature of scientific investigations was further assessed based on their answers to the 4th question on VOSI. An example of an acceptable answer is provided below (Table 2).

When we analyzed all participants' responses in this category, we concluded that all participants had an acceptable level of understanding about the subjective nature of scientific investigations. However, some participants' understandings were more sophisticated than others. For instance, while some students limited the subjectivity of the scientific investigations to the type of research that the scientists do, others emphasized the subjectivity of scientists in the type of methods they use to investigate a problem, or to analyze data. Similarly, some students pointed out that different scientists may use different evidence from the same data set, different scientists may not achieve the same level of precision in their data, which in turn could lead to different interpretations. Some students pointed out that different scientists may use different logic in making the connections between their hypothesis and evidence to draw conclusions. In sum, all participants emphasized the subjective nature of scientific investigations in their responses, however, half of them failed to acknowledge that scientists' personal biases may influence their observations.

Table 2 Sample response related to participants' understanding of the subjective nature of science

VOSI question	Student response
Do you think that scientific investigations can follow more than one method?	There is no one route to true scientific investigation due to the fact that people perceive and examine things differently. Paralleling this is the thought that any method used to make conjectures about the world around us can be considered scientific
If several scientists, working independently, ask the same question and follow the same procedures to collect data, will they necessarily come to the same conclusions? Explain why or why not	No, there is always error in experiments, and people interpret data differently based on their own education and learning experiences
If several scientists, working independently, ask the same question and follow different procedures to collect data, will they necessarily come to the same conclusions? Explain why or why not	No. Disparate procedures often lead to different results because of the methods used to attain the results
Does your response to (a) change if the scientists are working together? Explain	This scenario also does not necessarily yield the same results because of disparities in how people interpret information
Does your response to (b) change if the scientists are working together? Explain	No. The scientist can still obtain different results through different experiments

Tentative Nature of Science

Findings revealed that all participants but two had sophisticated understandings about the tentative nature of science. Those who emphasized the tentative nature of science provided diverse reasons. These reasons include “sophistication of new technologies can make new evidence available which could lead to modifications in old theory, and the existing theories can be modified based on new interpretations.” Another student said, “Theories can change because they are only a model that represents the way things work. Some students provided specific examples to communicate their understandings of the tentative nature of science. For instance, one student said, “Yes. Galileo’s theory concerning heliocentricity changed, in fact revolutionized, scientific theories of his day. In the same way, scientific laws that bind the world we live in can be changed through new discoveries.” Another student who also held a sophisticated view in this domain of NOS said, “For instance, when Neil Bohr came forth with his model of the atom, it became a theory, but later it was disproved and the actual structure of an atom was unveiled.” The results show that all participants but two held a sophisticated understanding about the tentative nature of science.

Science as Collective Reasoning and Knowledge Generation Activity

It is now well established at least in the science education literature that scientific discoveries and knowledge are the products of collective reasoning and shared understanding about the questions, processes and product of scientific explorations (Knorr-Cetina 1999; Longino 1990; Schwartz et al. 2008). Scientists share their knowledge and experience through lab meetings, conference presentations and journal publications (Dunbar 1997). Scientists often make their thinking subject to scrutiny by sharing their initial research questions with their fellow scientists, graduate students and the local and global scientific community (Dunbar 1997). By sharing their research questions and ideas with their fellow scientists, scientists are able to monitor their thinking and reasoning, revise their initial ideas or solidify them in collaboration with the members of their specific research groups or the global scientific community. It was hoped that by participating in these unique research activities, the participants would develop insights into the unique ways in which scientists collaborate, evaluate and elaborate on scientific discoveries during various stages of scientific inquiry.

Findings suggest that all participants recognized that science is a collaborative effort conducted by different members, each with special level of expertise, skills knowledge and power. However, not all participants

expressed a sophisticated understanding in this domain. One participant who believed science is the product of a collaborative effort said, “Scientific knowledge is the collective effort between various scientists. From my research experience, I learned that collaboration is crucial to help find solutions to multivariable problems.” Another student who also believed in collective nature of scientific knowledge said, “Scientific knowledge is probably the collective effort between many scientists. Since there needs to be many experiments to prove or disprove a hypothesis, I feel that there needs to be more than one scientist to establish data and conclusions.” Most of these students referred to their own experiences to justify their answers in addition to their beliefs. For instance, one participant said, “For example, many graduate students helped me in my microbiology experiment. If I had worked all by myself, I am sure that I would have messed up lots of data. Another participant who also highlighted the collaborative nature of science said the following:

At weekly board meetings the members of my research team voiced their opinions on how the experiment should run. One week one graduate student suggested moving my test tubes to a rack with different light strength, and in another Matt asked me to start recording data into an Excel spreadsheet. They formed assertions by gathering evidence and making an informed hypothesis, and they later validated assertions by observing the test tubes a few weeks later.

Although the majority of the participants expressed such a sophisticated view on the collective nature of scientific knowledge generation and the process of scientific inquiry, not all participants were able to elaborate on their responses at a level that the ones reported above did. Thus, there were variations in the quality of responses given by the participants as expected.

Participants’ Understanding of Various Aspects of Scientists’ Ways of Thinking

Scientists are constantly adding to our understanding of the natural and physical world by generating new knowledge and technologies that facilitate the process of knowledge generation. Scientists are able to do this partly because they have unique ways in which they think, reason and function while solving complex problems (Dunbar 1995; Kulkarni and Simon 1988). They apply these specific ways of reasoning in contexts where these special skills of reasoning are called for, such as when they are engaged in scientific inquiry in the university laboratories. Although scientists may use these specific reasoning skills during the process of scientific inquiry, some of their thinking may not be

visible to the novice scientists such as these high school students who spent two semesters in their laboratories. Therefore, it is important to explore the participants' understandings of the ways in which scientists think and function.

Findings suggest that the participants developed unique insights and understandings about the ways in which scientists think and function. These characteristics include: creativity and critical thinking (17/17), being methodological (15/17), questioning to verify data (17/17) and their interpretations (13/17). We elaborate on participants' responses related to scientists' ways of thinking in the following paragraphs.

Critical Thinking and Creativity

All participants (17/17), expressed that critical thinking and creativity is central to the practices of scientists. One participant said, "Scientists many times have to think outside the box to develop their hypothesis and design their experiments." The same student justified his answer by saying, "This is mainly due to the fact that when doing research they do not know what the outcome is going to be." Another student who also emphasized the creativity and critical thinking aspects of scientists said, "Scientists must think critically and creatively, and they must be able to understand the details and reasons for doing their experiments. From experience, I was able to learn how to think this way and how to solve problems."

The statements that emphasized the creative ways in which scientists think and reason was common across all other participants as well. However, only eight participants acknowledged that scientists' imaginations play a central role in the process of theory development.

Scientists are Methodological

Another common theme that consistently emerged across the participants' responses was that scientists are very methodological and that scientists must be very holistic in their approach to solving a problem. For instance, one student said, "They seem to be very thorough and think about all possibilities" Another one said, "I learned that scientists approach experiments with a very systematic process and not some arbitrary feeling." The findings suggest that although the participants thought that the scientists are methodological, they were able to understand that scientists look and analyze things from diverse perspectives. For instance one student said, "They are very methodological. They seem to look at a problem from about 3–4 different angles" Another participant, who also emphasized the open mindedness of scientists said, "they have to have a keen and open mind when performing

research." Yet another participant said, "I learned they always look at result in multiple angles, so that all areas of thought are covered."

Scientists Question

Another common characteristic of scientists that was emphasized by all of the participants was that scientists frequently question their methods, their data and the results of their analysis. With respect to questioning one student said, "I learned that scientists are always questioning their results throughout the entire research process." The participants emphasized that scientists use questioning to achieve precision and identify inconsistencies in data and interpretations. For instance one student said, "They always question. I learned this myself, too. I was always hesitant to accept a result and completed many replications of my data before making conclusions." Another participant said, "Scientists are EXTREMELY thorough with their note taking, and document every step they take. They don't think hastily or halfway." Yet another student said, "Scientists have to be very precise and collect data at the same time everyday in order to get the most accurate results. I learned these things through experience and time—sometimes I felt like my results were completely wrong and that I would have to do the whole experiment over again."

Verification of the experimental results is as important as the achievement of precision in a scientific experiment. The participants learned that scientists have skeptical habits of minds and that scientists use this skeptical habit of mind to collect quality evidence and to develop defensible explanations for the solution to the problems they are studying. For instance one student said, "I learned to never to jump to conclusions. I learned that a lot of thought is put into every step so that when it is time to publish the project all arguments have been defended." This particular student learned that scientific theories are subject to community scrutiny, therefore, scientists must verify the evidence and methods they use to collect evidence to support their theories through multiple methods. As evidenced in these statements given by the participants, the participants learned about various aspects of the scientific habits of minds employed by expert scientists.

The cumulative results related to participants' understanding of NOS and scientific inquiry are reported in Table 3.

Discussion and Conclusions

Scientific inquiry in the context of formal education in k-12 settings is limited to the "scientific method" in most cases

Table 3 Cumulative results related to participants' understanding of NOS and scientific inquiry

Aspects of science	Acceptable	%
Observation and experimentation	15/17	88
Difference between data and evidence	11/17	65
Multiplicity of methods of inquiry	13/17	76
Role of hypothesis in scientific inquiry	5/17	29
Process of hypothesis formation	16/17	94
Scientists' treatment of unexpected results	1/17	5
Process of theory formation	2/17	11
Subjectivity/objectivity	17/17	100
Tentative nature of science	15/17	88
Science as a collective knowledge building activity	17/17	100
Creativity and critical thinking	17/17	100
Scientists are methodological	15/17	88
Scientists constantly question to verify data	17/17	100
Scientists constantly question to verify the validity of their interpretations	13/17	76

(Abrams et al. 2007; Chinn and Malhotra 2002; Harding and Hare 2000; Rudolph 2005; Windschitl et al. 2008). The scientific method consists of a set of step-by-step procedures that range from making simple observations, asking a question based on these observations, controlling and varying variables, analyzing and interpreting data to reinforce conclusions about the scientific ideas expressed in science textbooks (Chinn and Malhotra 2002; Edmond 2005; Sandoval and Reiser 2004; Windschitl et al. 2008). Students engage in “scientific inquiry” by collectively completing a set of activities and either individually or collectively answering a set of questions about their observations at the end of the lab. This narrow view of scientific inquiry encourages the students to endorse a positivist view of science (Charney et al. 2007) in that it unintentionally encourages students to view science as a rigid, unquestionable body of valid knowledge generated by following a step-by-step process (Chinn and Malhotra 2002; Tang et al. 2008). Similarly, it encourages students to limit scientific inquiry to experimentation.

The two most prominent goals of science education reform efforts are to help students at all stages of education and their teachers to develop adequate if not sophisticated understandings about the nature of science and develop understandings, knowledge and skills to successfully conduct scientific investigations. The type of understanding and knowledge promoted in the reform documents goes beyond learning to use the scientific method and memorization of scientific facts. The reform documents and contemporary science education literature view science as a

human endeavor aiming to generate better explanations of the world around us through experimental and theoretical investigations (AAAS 1993; Abrams et al. 2007; Windschitl et al. 2008). Thus, learning science through inquiry goes far beyond learning to control and vary variables to make simple observations and forming simple conclusions in school laboratories (Lee and Songer 2003; Windschitl et al. 2008; Zachos 2000). Authentic scientific inquiry involves engagement in complex tasks and often requires more than controlling and varying variables. Scientists use sophisticated and multiple reasoning strategies to decide what and how to observe, to make judgments about how to relate their observations to what is already known about a natural phenomena while doing science in authentic settings (Dunbar 2001; Russ 2006). They use complex reasoning strategies to develop multiple hypotheses, choose the ones that have the best predictive power for explaining their observations, and to make complex sets of predictions and inferences to appropriately control variables, analyze their results, interpret the results of their experiments, make meaning of their analysis and develop evidence-based explanations (i.e., theories) (Chinn and Malhotra 2002; Dunbar 1997, 2001; Russ 2006). It follows that understanding the process and nature of science includes understanding of the ways in which scientists think and function, collaborate and challenge one another's claims to knowledge. The question then is: how do we ensure that high school students acquire the type of knowledge, skills and understandings needed for conducting scientific investigations?

The purpose of this study was to understand the impact of engagement in an authentic scientific research experience over a sustained period of time (i.e., two academic semesters) on high school students' understanding of the nature of scientific inquiry and nature of science (NOS).

The findings revealed that the participants developed abilities and knowledge to conduct scientific investigations. Similarly, they gained unique insights into the ways in which scientists think, reason and function (i.e., they question, they think and work hard, they are methodological). Almost all students engaged in the doing of science with the realization that their practices were consistent with the norms of scientific community. They were engaged in data collection, making observations, organizing, classifying and analyzing data and developing conclusions. They also engaged in such activities as judging the quality and reliability of evidence, coordinating between evidence and theory and contributing to the development of arguments that lived up to the standards of scientific community. For instance, they served as lead authors in the development of journal articles, conference proposals and poster presentations that lived up to the standards of scientific community. In addition, they engaged in practices such as making the

results of their inquiry public and subject to criticism and defend them through poster presentations in front of expert scientists.

Although the participants were able to develop knowledge and skills to conduct scientific investigations, they did not make the same progress in understanding the nature of science. For instance, the participants were only able to develop sophisticated understandings about the assumptions of science that are explicitly emphasized during the process of scientific inquiry. For instance, although the majority of participants understood the creativity that goes into the work of scientists, the importance of precision during data collection, the empirically-based nature of scientific knowledge, the subjective and tentative nature of scientific knowledge, the difference between experimentation and observation, only a small number of them understood scientists' treatment of unexpected results, the process of theory development and the role of hypothesis formation in the process of scientific investigations. Participants also held misconceptions about the methods of science and the difference between data and evidence. The majority of participants' understanding of scientific inquiry was limited to the scientific method. They did not see the complex and messy side of the scientific inquiry. Some participants' understanding of theory development was as simple as seeing patterns in data and drawing conclusions based on such data with limited reference to the socially negotiated nature of theory development. Although the majority of the participants acknowledged that scientific knowledge is the product of collective reasoning only few were able to elaborate on what that meant.

The aspects that the participants did not achieve competency in are the implicit aspects of science that are hard to learn by simply participating in actual process of scientific inquiry (Lederman 2007). These results lead us to believe that engagement in scientific inquiry in authentic contexts alone is not sufficient for novice scientists such as the ones studied in this study to develop adequate understandings of the implicit assumptions of science such as the steps and thinking that goes into the process of theory development, the difference between evidence and data and scientists' treatment of unexpected results. If the goal of such apprenticeship-based authentic scientific inquiry programs is to prepare future scientists, to help them to develop sophisticated understanding of the process and products of science, the curriculum should be structured in a way to explicitly challenge them to acquire the habits of minds employed by scientists in each step of the way through explicit instruction (Khishfe and Abd-El-Khalick 2002; Lederman 2007; Schwartz et al. 2004).

The participants' learning was limited perhaps because of an assumption made about scientists. One of the main assumptions of these apprenticeship-based models of

teaching inquiry-based science is that the university professors or senior scientists in national labs know how to mentor high school students and thus, to help them to experience, understand and use the epistemologies of science (Sadler et al. 2010). The results of this study suggest that the expert scientists are not as effective as they could be in helping novice scientists (i.e., high school students) to develop adequate understandings about all aspects of NOS and scientific inquiry. These scientists could become more effective in instilling the qualities that enable scientists to do science and thus generate new knowledge if they could teach the implicit assumptions of science in an explicit manner to the novice learners. Explicit instruction is also essential for ensuring the uniformity of learning outcomes in relation to the epistemologies of science and practices of scientists in such programs. That is because not all students are given the opportunity to experience the full spectrum of the scientific inquiry and are not explicitly challenged to learn about the unique ways in which scientists think, function and collaborate. Similarly, because of the variations in the tasks that the mentor scientists engage in, the cognitive activities that they engage in, the context in which they apply their cognitive skills, and the particular objects that they focus on (Schwartz et al. 2008), participants were able to develop understandings about certain aspects of science but not others.

The results indicate that the participants were exposed to different expertise, and contexts, each of which may only make specific types of knowledge and thinking explicit to the students. While some students engaged in very complex, multivariate inquiries, others engaged in simple observations of animal behaviors at the local zoo, collected and analyzed data and developed conclusions. Similarly, there were variations in terms of student autonomy while conducting their scientific investigations. While some students received very focused mentoring from expert scientists such as professors, only a graduate student mentored others. Engagement in diverse contexts and diversity in the type of mentoring received by the participants from the scientists at different levels of expertise may have influenced the variety in participants' understanding of NOS and scientific inquiry. For instance, expert, experienced scientists have specific ways of dealing with anomalous data than the novice scientists do (Dunbar 2001). Similarly, though scientists often use general set of principles to conduct an experiment and analyze data, some skills, ways of thinking and procedures are only unique to specific contexts. Schunn and Anderson (1999) maintain that each specific science related task requires a unique set of declarative and procedural knowledge and thus each experiment affords only certain type of knowledge and skills that can be acquired by the novice scientists (i.e., high school students). Explicit exposure to domain specific

facts, skills, schemata and ways of thinking acquired only through prolonged engagement in research in a specific domain of science can create invaluable learning opportunities for novice scientists such as the ones studied in this study. In order to achieve uniformity of learning outcomes across the participants the novice scientists should be guided to engage in learning activities that emphasize the global assumptions of the process and products of science. Learning opportunities in authentic settings must be structured in such ways that will allow the novice scientists (i.e., high school students) not only to witness how scientists design experiments, interpret data and develop, verify and defend theories but also understand why and how scientists engage in individual and collective cognitive activities they do to produce new knowledge. Only then the desired uniformity and quality of learning outcomes across participants may be achieved.

The results also suggest that for the novice scientists such as the ones studied in this study to develop sophisticated understanding of the epistemologies science they must receive explicit reflective instruction (Lederman 2007). However, even when expert scientists give such instruction to the novices, they may still develop naïve views about NOS and scientific inquiry. This is because expert scientists may not hold the type of emerging understanding of NOS and scientific inquiry that the science education community promotes (Schwartz et al. 2008). However, this is a problem that can be addressed by forming meaningful collaborations between scientists who are skilled and have an in-depth understanding of the process of scientific inquiry and science educators, who have contemporary understanding of NOS and how to teach it to the novices in an effective manner. If such collaborations can be formed, participants of such programs may be able to develop sophisticated understanding of the epistemologies of science, NOS and scientific inquiry. The challenge waiting science educators is the answer to the following question: How do we design meaningful collaborations between scientists who are interested in helping high school students to learn about scientific experimentation and science educators who are interested in helping aspiring high school students to develop sophisticated understanding of NOS? The answers to the questions such as this one are likely to make the experiences of novice scientists such as the ones studied in this project richer.

Limitations

Although the purpose of this study is not to generalize the results, there are several limitations to this study that needs to be mentioned. First, the participants in this study are

academically gifted students with successful academic histories as measured by their performance in school science and mathematics courses. Without more data it is difficult to claim that these results are due specifically to participation in scientific inquiry in an authentic scientific context. Second, students’ responses to an open-ended questionnaire can only give us a proxy of what they know about the process of science, nature of science and scientific ways of knowing. Students’ understandings about the process of science and ways of science can better be captured through interviews. Although interviews can provide more representative and meaningful data than an open-ended questionnaire can and allow for more in-depth analysis, we did not have resources to interview the participants. We want our readers to keep these limitations in mind as they think about the implications of these findings for contexts that may be similar to the one studied in this study.

Appendix 1: Understanding Nature of Science Survey

Directions

Please use the following likert scale for your answers to the survey questions/statements.

	_Strongly Agree	_Agree	_Neutral	_Disagree	_Strongly Disagree
PART A. Consider the following question for statements for questions 1-2: When two different theories arise to explain the same phenomenon (e.g., fossils of dinosaurs), what should scientists do? Show your answer by putting a check mark next to the likert scale comments.					
1.	Scientists must consider both theories because the two theories may provide explanations from different perspectives; there is no right or wrong answer in science. _Strongly Agree _Agree _Neutral _Disagree _Strongly Disagree				
2.	Scientists should not accept any theory before distinguishing which is best through scientific method because there is only one truth about a natural phenomenon. _Strongly Agree _Agree _Neutral _Disagree _Strongly Disagree				
PART B. Please indicate your level of agreement or disagreement with the following statements.					
3.	Scientists discover theories through careful observations and experimentation. _Strongly Agree _Agree _Neutral _Disagree _Strongly Disagree				
4.	No, scientists must develop scientific theories by interpreting facts , which they have discovered through careful observations and experimentation. _Strongly Agree _Agree _Neutral _Disagree _Strongly Disagree				
PART C. The following three statements are related. Please indicate your level of agreement or disagreement with the following statements.					
5.	Scientific theories may change in light of new evidence or new interpretation of existing evidence. _Strongly Agree _Agree _Neutral _Disagree _Strongly Disagree				
6.	Scientists can infer what has happened in the past, based on evidence. _Strongly Agree _Agree _Neutral _Disagree _Strongly Disagree				
7.	We cannot be certain that climate change is occurring because no one was around to observe climates of the past. _Strongly Agree _Agree _Neutral _Disagree _Strongly Disagree				
8.	Scientists are able to use existing information to make predictions about future natural phenomena. _Strongly Agree _Agree _Neutral _Disagree _Strongly Disagree				
PART D. Please indicate your level of agreement or disagreement with the following statements.					
9.	Scientists can abandon personal biases to make objective observations because they are well-trained professionals. _Strongly Agree _Agree _Neutral _Disagree _Strongly Disagree				
10.	Although subjectivity cannot be completely avoided in an observation, scientists use reliable methods to verify the results and ensure objectivity. _Strongly Agree _Agree _Neutral _Disagree _Strongly Disagree				
11.	No matter how the results are obtained, scientists will have to use the scientific method to verify them. _Strongly Agree _Agree _Neutral _Disagree _Strongly Disagree				

PART E. Please indicate your level of agreement or disagreement with the following statements.

12. Scientists must follow the scientific method to conduct their investigations
 Strongly Agree Agree Neutral Disagree Strongly Disagree

13. While the scientific method is useful in most instances, scientists sometimes invent their own methods to answer their research questions.
 Strongly Agree Agree Neutral Disagree Strongly Disagree

14. Scientists use their imaginations to develop scientific theories.
 Strongly Agree Agree Neutral Disagree Strongly Disagree

PART F. Please indicate your level of agreement or disagreement with the following statements.

15. Science is a collection of facts, theories and laws.
 Strongly Agree Agree Neutral Disagree Strongly Disagree

16. Science is a way to think about the world around us.
 Strongly Agree Agree Neutral Disagree Strongly Disagree

17. Scientists make explanations only based on evidence.
 Strongly Agree Agree Neutral Disagree Strongly Disagree

18. Scientific claims have to through rigorous process of justification before them become theories.
 Strongly Agree Agree Neutral Disagree Strongly Disagree

PART G. Demographic Questions
 Please place a checkmark next to the item that best describes you for each of the following statements.
 If your answer is Yes, place a checkmark in front of Yes and if your answer is no place a checkmark in front of No

1. I am a freshmen sophomore junior senior

2. I am White, African American, Asian, Hispanic

3. I am male female

4. I plan to pursue a science degree in college. Yes No

5. I plan to become a research scientist Yes No

6. I would consider my overall grades in school as Above Average, Average, Below Average

7. I would consider my overall grades in science courses as Above Average, Average, Below Average

8. I would consider my overall grades in math courses as Above Average, Average, Below Average

Appendix 2: Science Academy Students Only

Instructions for Students

We kindly ask you to describe your experiences as a high school scientist by answering the following questions. Select students who participated in the science internship program may be invited to write a chapter for the monograph.

Please answer the following questions as honestly as it is possible.

1. Can you please describe how you heard of this program? Who encouraged you to seek out for this opportunity?
2. How did you feel when you knew that you were accepted into the program? How did people around you (teachers, friends, family members) reacted to your decision to participate in this program?
3. What were your motivations for joining this program? Like, what were you expecting to get out of this program before joining?
 - (a) Can you elaborate on what you actually learned through this program compared to what you were expecting to learn? Any disappointments, surprises?
4. How long were you involved in this internship program?
5. Where at did you conduct your research project?
6. Can you tell us whether you conducted an original research project or did you work on an existing project? How was this decision made?
7. If you worked on a project that you designed yourself, how did you become interested in the topic that you researched in your project?
8. How did you go about designing your research, what questions were you interested in answering?
 - (a) How did you go about answering your question(s)?
 - (b) What type of data did you collect?
 - (c) How did you know that such data would help you answer your question?
 - (d) How did you analyze and interpret your data? What type of help did you get when you were analyzing data and from whom (prof, graduate student or others)?
 - (e) How did you learn how to use the instruments for collecting your data?
9. **What** did you learn about the ways in which scientists think, before, during and after data collection and analysis through your participation in this program? **How** did you learn it?
10. What did you learn about the ways in which scientists do their work (i.e., hypothesis formulation, design of research, data collection and analysis, writing conclusions), as a result of your participation in this program?
11. What did you learn about the topic you studied?
12. If you worked on your project as part of a team, what were your responsibilities? How and at what level did you participate in designing the question, deciding the type of data you needed to collect, how to collect and analyze data, and write the conclusions?
13. If you conducted an original research on your own, describe the parts of research for which you received help and the nature of help your received?
14. If you were to design this program, what would you change/modify to make it more beneficial for the program participants? Like, what would you like the professors to do differently, your teachers to do differently, graduate students to do differently, students to do differently?
15. What type of college degree and career do you plan to pursue? How has your participation in this research experience influenced your career decisions? What are some of the critical moments that influenced your decisions?

**PART THREE: Views of Scientific Inquiry
Questionnaire (VOSI): ALL GROUPS**

Name: _____

Class: _____

Date: _____

The following questions are asking for your views related to science and scientific investigations. There are no right or wrong answers.

Please answer each of the following questions. You can use all the space provided to answer a question and continue on the back of the pages if necessary.

1. What types of activities do scientists (e.g., biologists, chemists, physicists, earth scientists) do to learn about the natural world? Discuss how scientists (biologists, chemists, earth scientists) do their work.
2. How do scientists decide what and how to investigate? Describe all the factors you think influence the work of scientists. Be as specific as possible.
3. A person interested in birds looked at hundreds of different types of birds who eat different types of food. He noticed that birds who eat similar types of food, tended to have similar shaped beaks. For example, birds who eat hard shelled nuts have short, strong beaks, and birds who eat insects from tide pools have long, slim beaks. He concluded that there is a relationship between beak shape and the type of food birds eat.
 - (a) Do you consider this person’s investigation to be scientific? Please explain why or why not.
 - (b) Do you consider this person’s investigation to be an experiment? Please explain why or why not.
 - (c) Do you think that scientific investigations can follow more than one method? Describe two investigations that follow different methods. Explain how the methods differ and how they can still be considered scientific.
4. (a) If several scientists, working independently, ask the **same question** and follow the **same**

procedures to collect data, will they necessarily come to the **same conclusions**? Explain why or why not.

- (b) If several scientists, working independently, ask the **same question** and follow **different procedures** to collect data, will they necessarily come to the same conclusions? Explain why or why not.
- (c) Does your response to (a) change if the scientists are **working together**? Explain.
- (d) Does your response to (b) change if the scientists are **working together**? Explain.
5. (a) What does the word “data” mean in science?
(b) What is involved in data analysis?
(c) Is “data” the same or different from “evidence?” Explain.
6. Occasionally scientists encounter inconsistencies in their data. What do you think scientists do when some part of their data do not fit with what they expect (an “outlier” or inconsistency is found)?
7. Explain how scientists form hypothesis. What makes a good and a bad hypothesis?
8. Do you need to have a hypothesis to conduct a scientific investigation? Yes/No. Explain your justification in the space provided below.
9. How do you think scientists develop theories? Provide a detailed explanation about the way scientists develop theories
10. Can scientists develop theories without collecting data?—Yes—No. Explain the justification for your answer in the space provided below.
11. Can scientific theories change? If you think the answer is yes, why would scientists change established scientific theories such as Newton’s Laws? If you think the answer is No, explain why?

Appendix 3

See Table 4.

Table 4 Sample data evaluation rubric

	Acceptable answer: adequate understanding	Not acceptable answer: not adequate understanding
Prompt	Do you think there are multiple methods or one single method of inquiry that scientists follow? Explain	
Scientific method	There is no one route to true scientific investigation due to the fact that people perceive and examine things differently. Paralleling this is the thought that any method used to make conjectures about the world around us can be considered scientific In our project we tried to attach metal to C60 in two different ways: laser ablation and synthetic chemistry. Had we been successful, we would have used different methods to achieve the same ends. They were scientific because we set out to prove something, observed results and concluded something	I think they should all follow the scientific method There is only the scientific method. There are always variations within experiments but they should all follow the same format to be considered scientific. For example, one scientist may discover something by chance and then test it, and another scientist may make a discovery after years of research

Table 4 continued

	Acceptable answer: adequate understanding	Not acceptable answer: not adequate understanding
Prompt	How do scientists develop theories? Explain	
Scientific theories	Scientists probably develop theories after years of careful observations and finding patterns in their data. After all, you can't just throw out a theory without first explaining where it came from and what kind of data you have as backup. For example, a scientist spends 10 years on a tropical island, observing the different kinds of monkeys present. Out of the many species on the island, two are the most successful—the brown-haired monkeys and the white-haired monkeys. The scientist proposes that these species are the most sociable species of monkeys because they are always seen grooming and taking care of each other. With nearly 10 years of solid proof and observations, this scientist has developed a logical, possibly true theory	They develop theories by observation of their surroundings. They think of things that occur naturally and try and implement these observations in their field. For instance, cobalt has a high curie temperature; so adding it to $Tb_6Fe_{0.625}Co_{0.375}Sb_2$ should increase the curie temperature of that alloy. Theories do not have to have any solid proof. After all, most scientists assume that all theories are just scientific guesses. For example, Neil Bohr's theory of the atomic structure was unproved during his time, but people still accepted it as fact
Prompt	Can scientific theories change? If you think the answer is yes, why would you think the answer is No, explain why?	
Tentativeness	Yes. Galileo's theory concerning heliocentricity changed, in fact revolutionized, scientific theories of his day. In the same way, scientific laws that bind the world we live in can be changed through new discoveries I think scientific theories could change, but if done correctly and accurately then they don't need to be changed, such as Newton's Laws. They could change in the sense that there is another way of thinking about the scientific phenomena. They could change also to better modify the scientific theory	No, theories are almost fact

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