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High School Student Participation in Scientific Research Apprenticeships: Variation in and Relationships Among Student Experiences and Outcomes

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Abstract Research apprenticeships for secondary students provide authentic contexts for learning science in which students engage in scientific investigations with practicing scientists in working laboratory groups. Student experiences in these research apprenticeships vary depending on the individual nature of the laboratory in which students have been placed. This study explores potential relationships among student experiences in apprenticeship contexts and desired student outcomes (e.g. science content knowledge, understandings of nature of science, and aspirations for science oriented career plans). The following two research questions guided the study: How do participant experiences in and outcomes resulting from an authentic research program for high school students vary? How does variation in participant experiences in an authentic research program relate to participant outcomes? Primary data sources were student and mentor interviews in addition to student generated concept maps. Results indicated that the greatest variance in student experiences existed in the categories of collaboration, epistemic involvement, and understandings of the significance of research results. The greatest variation in desired student outcomes was observed in student understandings of nature of science and in students' future science plans. Results suggested that collaboration and interest in the project were experience aspects most likely to be related to desired outcomes. Implications for the design of research apprenticeships for secondary students are discussed.

Keywords Apprenticeship · Authenticity · Nature of science · Research experience · Science careers · Scientific research

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How similar inquiry-for-education experiences are to scientific inquiry, as practiced professionally, is often used as a criterion for assessing science learning opportunities (Hofstein and Lunetta 2004). The underlying assumption is that inquiry-for-education ought to reflect the activities, intellectual demands and values of "authentic science" (Brown et al. 1989). Scholarship that has explored this question of authenticity has identified a number of ways in which classroom instantiations of inquiry deviate from scientific inquiry. These critiques include students not being involved in the conceptualization and development of researcher questions (Chinn and Malhotra 2002), the use of cookbook-style laboratory procedures rather than negotiating issues of research design and methods (Hofstein and Lunetta 2004), and the use of classroom inquiry experiences for the sole purpose of illustrating science concepts (Haigh et al. 2005). A survey of inquiry practices in classrooms from around the world showcases common challenges as well as nuanced differences across international sites (Abd-El-Khalick et al. 2004). In both Lebanon and the United States, inquiry activities are often "hands-on" but they are not frequently "minds-on" as students tend not to be epistemically involved in the design of laboratory activities. In Venezuela, a lack of clear goals for inquiry have limited the authenticity of student experiences in classrooms. In Taiwan, pressure to teach to high-stakes standardized tests has tended to shift teacher attention away from laboratory investigations.

Efforts to engage learners in more authentic scientific practices have been more successful in other national contexts. For example, laboratory experiences for high school students in Israel successfully model scientific inquiry (Abd-El-Khalick et al. 2004), particularly related to the generation of research questions (Hofstein et al. 2005). In Australia, efforts to embed chemistry instruction in meaningful contexts have created opportunities for students to participate in independent and extended experimental investigations (King et al. 2008). In Germany, educators have experimented with structured pre-experimental activities that have resulted in students formulating research questions and designs (Neber and Anton 2008). In the UK, scientific investigations in school science have been prioritized in the national curriculum. Researchers believe that these investigations have the potential to result in development of both procedural and conceptual understandings of science particularly in terms of the role of evidence (Duggan and Gott 1995; Gott and Duggan 1996).

The programs discussed thus far focus on attempts to make school science more like authentic science. A different approach with similar aims is to create learning opportunities in the midst of science as it is being practiced. We identify this approach as *research apprenticeship.* Apprenticeships of this sort involve partnering students with mentor scientists to conduct scientific investigations.

Conceptual Framework

Pairing learners with mentor scientists allows students to participate in the authentic practices of science "at the elbows" of those who are fully immersed in the culture of science (Barab and Hay 2001). The activities of a research apprenticeship are authentic in terms of the nature, timing and site of activities. Students engage in the collection, analysis and/or modeling of data relative to active research programs guided by genuine (i.e. unanswered) questions. These experiences are similar in many respects to apprenticeships of old in which master craftsmen and artisans worked closely with apprentices to introduce the novices to the tools, essential skills, common practices, shared wisdom and culture of the craft or discipline (Lave 1991).

Historically, apprenticeship has been the dominant model for the education of graduate students in the sciences (Feldman et al. 2009). Providing apprenticeship experiences for secondary and undergraduate students of science has been a more recent development, with programs that offer authentic research opportunities for these audiences increasing in frequency over the last two decades (Sadler et al. 2010). Student access to apprenticeship experiences is often facilitated through institutionalized programs, which can provide structures that influence and guide student experiences.

We recently completed a review of studies of authentic science research experiences for secondary and undergraduate students (Sadler et al. 2010). In this review, over fifty empirical studies spanning a time period of nearly fifty years were examined. The review documented several learning outcomes associated with apprenticeships including increased understandings of science content and nature of science as well as development of interest in science related careers. Syntheses of these findings suggested that the duration of research apprenticeships (Ritchie & Rigano 1996; Russell 2006), the extent to which desired outcomes were explicitly supported (Bell et al. 2003; Grindstaff and Richmond 2008), and epistemic involvement of students in apprenticeship activities (Hay and Barab 2001; Moss et al. 1998; Ryder and Leach 1999) were significant mediators of the success of the programs.

Literature Review

The following review of empirical research on science research apprenticeships for secondary students is organized based on the outcomes and experiences investigated as a part of our work. Unfortunately, few research studies focus on the variation in individual student experiences within apprenticeship programs and their relationships to student outcomes; therefore, our review of experiences is necessarily brief. It should be noted that a commonality across much of the research reviewed is a focus on student participant perspectives on their experiences within apprenticeship programs. A final section of our review presents studies that have explored mentor perspectives on apprenticeship experiences in anticipation of some of the data collection procedures we adopt as a part of this study.

Outcome: Nature of Science

The epistemology of science or the ways of knowing science have typically been referred to as nature of science (NOS; Lederman 1992). Science educators have identified several aspects of scientific knowledge and practices that help operationalize NOS as a meaningful construct for researchers, teachers and students. Consensus NOS aspects include the empirical, creative and tentative natures of science knowledge; distinctions between theories and laws: social and cultural foundations of science knowledge, and the “myth” of the scientific method (Lederman et al. 2002).

Some evidence has emerged to suggest that participation in research apprenticeships positively affects understanding of one or more NOS aspects. Gains in the understandings of the social and cultural foundations of science are supported when participants in research apprenticeships come to view themselves and scientists as part of a larger community within which exists a spirit of collaboration (Charney et al. 2007; France and Bay 2010; Richmond and Kurth 1999). Students have also shown gains in understandings of the tentative nature of science through reflective participation in research apprenticeships

(Charney et al. 2007). An additional aspect of NOS discussed in the literature is the complexity involved in the generation of science knowledge (Barab and Hay 2001; Richmond and Kurth 1999). In these studies, apprenticeship participants come to understand that the generation of scientific knowledge does not necessarily take place in a set step-wise procedure. Barab and Hay (2001) discuss how apprentices learn that scientists often gain more from findings that challenge their hypotheses than they do from confirmatory findings. Although the complexity of knowledge generation is not typically mentioned among consensus lists of NOS aspects, we along with other researchers (Richmond and Kurth 1999; Ritchie and Rigano 1996) view student learning about this construct as an important component of scientific epistemology. Much of the data used to examine claims related to NOS relies on student self-reported interview data. However, one of these studies use a form of the Views of Nature of Science Questionnaire (VNOS; Lederman et al. 2002) to substantiate their findings (Charney et al. 2007).

Outcome: Content Knowledge

The designers of research apprenticeship programs typically assume that participants will leave the experience with better understandings of scientific content. Research tends to support this assumption; however, questions regarding the validity of some of these conclusions have been raised (Sadler et al. 2010). Some studies rely on self-report data without other forms of corroborating evidence (Abraham 2002). Other research has employed more sophisticated designs that provide more compelling evidence of content knowledge gains. Lewis et al. (2002)) document mentor perceptions of student learning in support of their exploration of student perceptions. Some researchers have employed in-depth, ethnographic methods to document apprenticeship learning over time (Bleicher 1996; Grindstaff and Richmond 2008; Ritchie and Rigano 1996). Charney et al. (2007) provide one of the few quantitative studies of content learning. In this investigation of students participating in a molecular biology apprenticeship program, pre- and post-experience scores on sample Advanced Placement biology test questions reveal statistically significant gains in understandings of molecular genetics and biochemistry.

Outcome: Future Plans

For many of the programs that create opportunities for students to engage in authentic research, a stated aim is to promote future participation in the sciences (Sadler et al. 2010). Future participation may entail choosing to study more science, selecting a science major in college and/or pursuing a career in the sciences. Many studies of undergraduate apprenticeship programs examine the extent to which this goal is met (e.g. Hunter et al. 2007; Russell 2006; Seymour et al. 2004). These studies suggest that apprenticeship experiences support preparation for and interest in pursuing future science opportunities. There is much less research on this topic related to programs for secondary students. A few studies document that participants in research apprenticeships for high school students tend to be interested in pursuing science majors in college and careers in science (Abraham 2002; Cooley and Bassett 1961; Davis 1999), but this work does not document ways in which the apprenticeship experience may have influenced those plans. Stake and Mares (2001) explore how student career goals shift as the students participate in an apprenticeship program. In this study, students become more aware of the realities of working in a specific field of science and more actively consider alternative career choices. Specifically, students shift away from career goals associated with becoming a physician while still maintaining science career goals in general.

Experiences

Although most research studies do not directly examine individual experiences within apprenticeship programs, some attempt to link desired outcomes to aspects of the experience. For example, in a case study of a single student involved in a summer research apprenticeship, Bleicher (1996) finds that student learning of science content is dependent upon the communication that occurs between the student and the mentor. Another report examining two high school students involved in a lengthy research apprenticeship reveals that gains in conceptual understanding of chemistry content are directly linked to the mastery of lab procedures and techniques that accompany a gradual transfer of expertise from the mentor to the students and subsequent feelings of ownership and independence observed in the students (Ritchie and Rigano 1996). Findings such as these highlight the significant role mentors play in apprenticeship experiences.

A few studies suggest the need for collaboration as an important experience within apprenticeships. Grindstaff and Richmond (2008) report that explicit peer-collaboration and support play a role in student learning of science content. Similarly, Ritchie and Rigano (1996) describe development of sophisticated understandings of chemistry that occur only after participants spend enough time to become fully immersed in the culture of their laboratories. The degree of collaboration afforded by student immersion in laboratory settings may be associated with the positive gains in content knowledge observed among apprenticeship students.

Epistemic involvement of students in research processes is an experience aspect of apprenticeships often associated with the development of sophisticated views of NOS (Barab and Hay 2001; Bell et al. 2003; Ritchie and Rigano 1996; Ryder and Leach 1999). These studies suggest that the ideal apprenticeship context is one in which the student takes an active role in developing research questions, the designing procedures, and interpreting results. However, many studies report or imply that apprenticeship programs for secondary students usually cannot engage participants in these epistemically demanding activities because of limitations in time and student expertise (Barab and Hay 2001; Ritchie and Rigano 1996).

Mentor Perspectives of Research Apprenticeships

Much of the research associated with science apprenticeships is based on data derived from students. Few studies of apprenticeship programs for secondary students make use of data derived from mentors. Bleicher (1996) analyzes field observations of students participating in an apprenticeship that includes mentor interactions. These data are used to support claims that students adopt the discourse practices of their mentor. Lewis et al. (2002) uses mentor evaluations of student understandings of content. Some of the research associated with undergraduate apprenticeship programs has made more effective use of data from mentors to corroborate student self-reported information (e.g. Hunter et al. 2007; Ryder and Leach 1999).

Research Focus

In reflecting on the extant literature, we do not believe that sufficient attention has been directed toward (1) understanding individual experiences within research apprenticeships, (2) how these experiences vary across individuals and (3) how variation in experiences relates to the outcomes students achieve. The purpose of this study is to explore student experiences and outcomes associated with participation in a science research apprenticeship program. We explore how several high school students participating in an apprenticeship program experienced the opportunity, how these experiences varied among individuals and possible relationships between learner experiences and outcomes. The following research questions guided our investigation.

1. How do participant experiences in and outcomes resulting from an authentic research program for high school students vary?
2. How does variation in participant experiences in an authentic research program relate to participant outcomes?

Experiences and Outcomes of Research Apprenticeships

Based on our framework of research apprenticeships for secondary students as informed by our review of the literature, we, as researchers, selected experiences and outcomes on which to focus as a part of this investigation. This identification of outcomes and experiences informed our design of interview protocols. However, we designed these protocols to be open-ended and allowed participants opportunities to speak freely with the expectation that additional experiences and outcomes could emerge from an inductive analysis of their individual accounts of participation in research apprenticeships. This process will be more clearly described in the data analysis section of the report, but for the purposes of organizing the paper, we identify the full range of experiences and outcomes included in our analyses. This report analyzes the following outcomes of research: understandings of nature of science, science content knowledge, and future plans in science. The individual experiences explored are the degree of mentor support received, the nature of collaboration experienced, epistemic involvement of the student, student understanding of project significance, and student interest in his/her research project. The manner in which we have operationalized constructs within these experiences and outcomes as well as the methods we have used to explore them have been influenced by our understandings of situated perspectives on knowing and learning (Brown et al. 1989; Lave and Wenger 1991).

Methods

Study Context

This study was conducted in the context of the Student Science Training Program (SSTP). SSTP is a seven-week summer residential research experience at a major university in the Southeastern United States. The program is designed for high school 11th and 12th grade students (age 16–17) who excel in math and science. Each year approximately 100 students are accepted into SSTP based upon teacher recommendations, application essays, and past academic performance. The program charges tuition and fees, but some participants with financial need receive scholarships that cover these costs. Individual students are paired with a science faculty member and are assigned to a specific research project within the mentor's laboratory. On average, students spend thirty hours per week in their assigned laboratories. In addition, students attend lectures and seminars on various science topics. Students present their research findings in an original paper and a formal oral presentation at the end of the program.

Sampling and Participants

This study focused on two cohorts of high school students who participated in the SSTP during the summers of 2007 and 2008. Each year, we identified nine students from among those who consented to participate in the study. We purposefully sampled scholarship recipients and individuals who had not received financial support. Individual selections from within these groups were made randomly. Because the scholarships targeted students from groups underrepresented in the sciences (racial and ethnic minority groups), students from these groups were overrepresented in our sample relative to rates of participation in the SSTP program. Of the 18 participants over the two-year project, three were African American, four were Hispanic, and seven were female. Five of the participants were in an International Baccalaureate program and eight had taken Advanced Placement classes. The most common reason given by participants for enrolling in the program was to explore career options in science (five of 18 participants). Another motivating factor was to receive dual enrollment college credit (two of 18 participants). One student was forced into participation by his parents. Student research assignments varied from biological science and medical research to materials engineering and computer programming. Table 1 summarizes each of these participants and the nature of their specific research.

Data Collection

During the summer of 2007, student participants were interviewed twice during their apprenticeship. The first of these interviews was conducted during the first two weeks of the program and the last was conducted during the final week. During the summer of 2008, students were interviewed in the middle of the experience (during the fourth or fifth week), in addition to the beginning and the end of the program utilizing three different semi-structured interview protocols. As a part of the 2008 interviews, students constructed concept maps illustrating the science content underlying their research. Students created an initial map during their first interviews and were then encouraged to revise these maps during a subsequent interview. The interview protocols from both years are summarized in Appendix A. Students from the 2008 cohort were also observed in their laboratories and as they conducted their final research presentations. All 2008 faculty mentors were asked to participate in interviews following the program. Three mentors responded positively to this request. Ultimately, we interviewed four mentors (three faculty and one graduate student) working with three students. The protocol used for the mentor interviews is presented in Appendix B.

Concept Mapping as a Data Collection Tool

Following data collection in 2007, we were not satisfied with the self-report data related to participants' development of content knowledge derived through our interviews. However, the diversity of individual research projects made it impractical to use a common assessment as a means of measuring participant gains in content knowledge. To address these issues, we employed a concept-mapping task that challenged students to synthesize and represent science understandings related to their research. Concept maps are graphic organizers useful in communicating knowledge by offering a strategy for the visual display of relationships among concepts (Novak and Canas 2007). We provided opportunities for students to create concept maps at two distinct points (beginning and end of the

Table 1 Student participants

Student	Gender	Ethnicity	Year	Scholarship Recipient	H.S. Science Experience	Motivation to attend SSTP	Research Project Science
1.Gabriela	F	His	2007	Yes	AP classes	Experience college life	Biological Science/Genetics
2.Hector	M	His	2007	Yes	AP classes	Encouragement from boss	Ecology
3.Beth	F	AA	2007	Yes	AP classes	Encouragement from principal	Entomology
4.Jessica	F	AA	2007	Yes	Gen Ed	Experience college life	Medical Research
5.Rachel	F	AA	2007	Yes	AP classes	Wanted a vacation	Ecology
6.Vlad	M	Cau	2007	No	AP classes	Develop research project for competition	Materials Engineering
7.Amy	F	Cau	2007	No	Gen Ed	Explore career options	Medical Research
8.Mary	F	Cau	2007	No	Honors classes	College admission	Medical Research
9.John	M	Cau	2007	No	IB program	College admission	Biochemistry
10.Claudia*	F	His	2008	Yes	IB program	Explore career options	Biological Science
11.Roberto	M	His	2008	Yes	AP classes	Receive College Credit	Materials Engineering
12.Danielle	F	Cau	2008	No	IB program Science Club	Family Expectation. Family had been in program	Biological Science
13.Stephanie	F	Cau	2008	No	AP classes	Friend had been in program	Microbiology
14.Patrick*	M	Cau	2008	Yes	IB program	Parent requirement.	Biomedical research
15.Jeffrey*	M	Cau	2008	Yes	Gen Ed Marine science camp	Explore career options	Medical research
16.Sarah	F	Cau	2008	No	AP classes	Explore career options	Biological Science
17.Jenny	F	Cau	2008	No	IB program	Explore career options	Medical research
18.Mike	M	Cau	2008	No	Gen Ed	Receive College Credit	Computer Science

* = Mentor was interviewed to corroborate student interview data. His = Hispanic. AA = African American. Cau = Caucasian.

apprenticeship program) in order to document ways in which the students' ideas regarding the science content related to their projects evolved.

Data Analysis

Our analysis of data was guided by the grounded theory approach (Corbin and Strauss 2008). The process involved multiple iterations of data analysis, generation of codes, refinement of codes and development of theoretical constructs to account for observed patterns. We constantly compared emergent codes to available data and tested developing explanations against the full data set. Analysis progressed in a series of six phases; these phases are outlined below.

Two researchers began analysis through open coding of a sub-set of the 2007 data: transcript sets and field notes from two randomly selected. The two researchers independently examined the data sets and generated initial codes to characterize student experiences and outcomes. The researchers then met to discuss, revise and compare the preliminary codes, and establish a consensus code list. This process was mediated by a third researcher who served as a peer debriefer (Lincoln and Guba 1985). In the second phase, the researchers used the consensus codes to independently analyze data sets from two other participants from the 2007 cohort. These coded transcripts were compared and an inter-rater consistency of 96% was established. Given the high rate of agreement, a single researcher coded the five remaining data sets from 2007.

Based on trends that emerged in the coded data, we decided to create ordinal scales to help characterize the observed variation. We applied three-level ordinal scales (high-medium-and low) to some of the experience and outcome categories. In the third phase of analysis, one of the researchers assigned these ordinal ratings to data collected from the 2007 cohort.

Following analyses of 2007 data, we altered some of the data collection procedures for the 2008 cohort including adding a third interview, concept mapping activities and mentor interviews. Despite these changes, the general coding schemes developed in the first year were robust enough to account for most of the 2008 data. Data derived from the concept maps offered the only exception; for analysis of these data we adopted a different strategy (described below). In the fourth phase of analysis, one researcher coded the 2008 interview and observation data using the consensus code list and ordinal descriptors developed in the previous year. In order to establish trustworthiness of these analyses (Lincoln and Guba 1985), another researcher independently analyzed four data sets. Inter-rater consistency for the assignment of the consensus codes was 100%; inter-rater consistency for the application of the ordinal classifications was 88%.

In the fifth phase of the analysis, a researcher examined the mentor interview data. The same basic experience and outcome codes developed from the student data were used to help characterize the mentor data. The primary purpose of the mentor interview data was to substantiate and or challenge claims derived from the student data. Given this focus, a second researcher reviewed and discussed these analyses as a form of peer debriefing (Lincoln and Guba 1985).

We examined the concept maps in the final phase of analysis. Initially, we examined the maps for accuracy. Given the extensive science background of the authors (graduate level experience and research in chemistry, biology, and medicine), we felt confident in our general appraisal of the accuracy of the science content represented. Individual maps represented scientific ideas accurately, but they offered a wide range of detail and structure. Consistent with other research using concept maps (Rice et al. 1998; Yin et al. 2005), we analyzed multiple dimensions of the student maps. Borrowing from the assessment scheme of Yin et al. (2005), we classified concept map structures as linear, circular, hub and spokes, tree or network. These five classifications represented progressively more complex map designs. In a linear structure, concepts are connected in one straight chain. In a circular structure, the last concept in a chain is connected back to the top. Three or more concepts radiate out from a central concept in a hub and spokes structure. A tree structure has branches attached to a central chain. Finally, a network showcases interconnected links between multiple concepts. In addition to assessing structure, we documented numbers of concepts, labeled links, and discipline specific constructs presented in the maps. We define discipline specific constructs as concepts that correspond to specialized ideas within a particular field. We operationalized discipline specific constructs by identifying terms used within the maps that students would very unlikely have experienced in everyday conversations. Therefore, “metal”, and “malaria” were not identified as discipline specific constructs whereas “defect formation energy of metal oxides” and “protease plasmepsin” were. By themselves, none of the dimensions that we used to characterize the concept maps provide a robust measure of a student’s knowledge, but our multi-dimensional approach offers a means of assessing the structure and depth of a student’s understanding.

Results

Variation in Student Experiences

We identified five experience variables: (1) the mentor support a student received, (2) the amount of collaboration within a student's laboratory placement, (3) the epistemic involvement of a student, (4) a student's understanding of the significance of research results, and (5) a student's personal interest in the project. We discuss each of the experience variables below.

Mentor Support

Each student was paired with a faculty mentor. Some faculty personally supervised the student placed in their labs, while others delegated mentorship responsibilities to graduate students. Regardless of the identity of the mentor, varying degrees of mentor support were offered. A high degree of mentor support was documented when a mentor regularly interacted with a student and was willing to field questions, discuss the project, etc. Vlad, a student rated high on this variable, said, "I see him like pretty much every other day. I go to his office and ask about something…" This data was corroborated by mentor interview data when available as exemplified by the quote from the faculty mentor who worked with Patrick, another student rated high in mentor support: "He [Patrick] would come and see me a couple times during the week."

Other students experienced a larger amount of mentor support at the beginning of the program than they did at the end. For example, Stephanie said, "After he [her mentor] showed us once, he let us do all the stuff by ourselves." These students were given a brief introduction to the research by their mentors but then left alone for the most part. A rating of medium was assigned to this level of mentor support. These data were also supported by mentor interview data. Claudia's mentor offered the following characterization of her approach to mentoring: "I'm trying to get my work done and get her moving along as well. So I treated her like any technician I have had in the past. I show her once or twice and she's on her own."

Only one student experienced a level of mentor support that we rated as low. When Rachel was asked who helped her figure out how to do scientific research she replied, "If it's not the high school student Hector, then it's the grad student [her mentor]". Hector was another participant of the SSTP program who was placed in the same lab as Rachel. Rachel tended to turn to Hector before seeking the support of her actual mentor. She later discussed going to her SSTP counselor when she had questions. Additional representative quotes for the three categories of mentor support are presented in Table 2 along with quotes for all of the other experience variables and one outcome variable (NOS) which was also rated with a three-level scale.

Collaboration

Collaboration represented the extent to which a student felt accepted as part of a working research team. We rated students high on this variable if they felt like they were collaborating extensively on a project with others and low if they felt like they were working in isolation. The data did not warrant development of a "medium" category. Jeffrey, a student rated high in this category, described his experience in the following way. "I really got into the thick of things. I was doing things that were contributing to the lab."

Vlad described the collaboration he experienced as a process of moving from being a "watcher from the outside" to really "contributing to what's being done." Patrick described this as being "part of the family" and Jenny discussed how she eventually became "just like one of them [more permanent lab members]." These data were corroborated by the interview with Jeffrey's mentor, who talked about Jeffrey as a legitimate member of the research team. The mentor went so far as to include Jeffrey as one of the lab members to whom he would go to "bounce ideas off."

In contrast, Claudia, who was rated low in collaboration, said, "I'm like in the field without any contact with any other person" and "I don't work with any other students in my lab." Even though Claudia felt supported by her mentor at the beginning of her program, her experience was one of isolation and she did not feel like she was working collaboratively with anyone on her project. Interestingly, Claudia's mentor explained the situation very differently. The mentor discussed how Claudia "progressed over the summer" from a "high school kid" to a working contributor. Additional representative quotes for collaboration are presented in Table 2.

Epistemic Involvement

Epistemic involvement references the extent to which students were involved conceptually in their research. Student participation in the generation of research questions, selection and/or design of research methods, analysis of data and generation of conclusions constituted epistemic involvement. In contrast, students who did little more than follow set procedures for collecting data were likely to not be epistemically involved in their projects. Epistemically involved students discussed working on projects with uncertain outcomes and felt like they were contributing meaningfully to the progress of the work. Stephanie, for example, said of her project, "it's never been done before. They [her laboratory mentors] don't know if it's really going to work." Danielle similarly described her research project as consisting of all "new work". Because of the uncertainty of her project's outcome, she was given the freedom and responsibility to explore different methods. When speaking of her mentor, Danielle reported, "She really lets me do everything hands on… I learn it for myself. I make my own mistakes."

Others felt like they could make few contributions to the design of their projects even if it was new research with uncertain results. These students were assigned a medium rating. They felt that the projects to which they contributed were open areas of inquiry but they were limited in terms of their ability to assume epistemically demanding tasks associated with moving the agenda forward. For example, Sarah said, "they [members of her lab group] told me what to do, like they already had it planned and I just went along with it."

Finally, some students were working on replication projects with known results. These students were given verification tasks related to completed research projects and were assigned a rating of low in this category. Roberto, for example, said his research was just "reproducing what has been done." He went on to say that his research therefore could never be published. Two of the mentors that we interviewed justified the low epistemic involvement that was experienced by students placed in their labs. For example, Patrick's mentor described how the design and interpretation of data was something that high school students were not ready for: "As far as actually interpreting that data and relating it to an overall big picture doing an analysis, that I don't think they can do right away. It's too short of a time period for them to really get up to speed and they probably don't have the background to really interpret the data properly."

Table 2 Representative quotes of experience and outcome ratings

Experience	Rating	Exemplar Quotation
Mentor Support	High	Patrick: "I had no idea what to do, but the professor was really cool. He was really patient, because I kept asking him what these things were and just asking, asking, asking. And he always answers them. He is really patient even though I have to ask him five times."
	Medium	Claudia: "Like almost every day I do the same activity over and over again so I don't really need her help that much."
	Low	Rachel: "If the grad student isn't able to help me then I'll ask my study group leader." "I've met him (the faculty mentor) twice." "He's always in his other (lab)."
Collaboration	High	Gabriela: "I feel like I fit right in…I feel really comfortable in there and the people are really nice and I'm doing what they're doing."
	Low	Rachel: "At one point it was like helping them. Now our projects are not really helping them. We're on our projects." "I don't say much. I don't talk to anyone."
Epistemic Involvement	High	Hector: "he (the graduate student mentor) would ask us what we thought was best to do after what we had just did. So he'd always ask us that, and so we took like a very active role in what we were going to do with our experiment."
	Medium	Jeffrey: "It's well underway. So pretty much, they're incorporating me as much as they can but I'm pretty much starting in the middle of the experiment, trying to catch up to what they were doing."
	Low	Amy: "I really didn't have any new ideas to bring into the experiment, the methods were pretty much set. You know just following the methods. I didn't really feel the need to like come up with a new way. I felt like the old ways worked, if they just had to be done."
Result Significance	High	Jeffrey: "It's big stuff. This is like the first step towards making a new treatment (for malaria)." "We're doing something that I can like directly see the applications to. I know it's going to be important and I can see how it's going to be important."
	Medium	Interviewer: "What do these results mean?" Jenny: "Well basically there's not really much research done as to why there might be so many microglias in the microcampus, but that is the area where all the microglia probably should be, because that's where all the neurons are made…" (no practical explanation)
	Low	John: "It's (his research) valuable on a scale, but it's kind of like a scale that's way out there. Like it might become valuable, but it's a long stretch. It's a long shot for it to be valuable."
Interest in Project	High	Patrick: "But after I found out like what I'm doing, what the work was about I've got such a huge interest. I'm almost thinking about it all the time and thinking about what I'm going to do tomorrow."
	Medium	Interviewer: "Do you find this work interesting?" Sarah: "I like it, but nothing I would want to do for the rest of my life."
	Low	Roberto: "I wanted to do more hands on and stuff…and I'm working on the computer all day."

Outcome	Rating	Exemplar Quotation
NOS	High	Hector: "How they teach it (science) to us it's not exactly how you use, like how they say you have to have a hypothesis and then statements and you can't veer off any way, it's just all straight. And when you're actually doing the scientific work, there are so many things that come into play. You can't just go straight, you have to look at this and

Table 2 (continued)

Outcome	Rating	Exemplar Quotation
		this and that and all these variables and everything put together."
	Medium	Roberto: Naïve: "Its (science) just like actually looking for things that have already been done." Sophisticated: "I believe that research is interesting because it's something completely new and you're expanding human knowledge."
	Low	Claudia: "Just to have the same monotonous routine every day it kinda like bores me you know." "More social interaction and things like that."

Result Significance

An understanding of the significance of the student's research project was another important experience variable that emerged from student interview data. Some students grasped the broader context and purpose of their research, and these understandings seemed to be a motivating factor for them. Others were unable to discuss the significance of their research, and some went so far as to say that they didn't think that the research that they were doing held any significance to the world outside of their highly contextualized laboratory.

Students who clearly articulated understandings of the significance of the research that they were conducting were given a rating of high for "result significance." Amy, for example, who was developing a model for the structure of a virus, said her work was a "major contribution…to have this structure, it tells us so much." Other students who received this rating were able to discuss practical applications of their findings as in the case of Vlad who related the work he was doing with the optical properties of polymers to the creation of new materials for eyeglasses. Mentor interview data corroborated the student reported understandings of significance. Jeffrey's mentor, discussed the importance of emphasizing the global and human connections of the research in which students engage. According to him, these connections allow students to "see what's going on in the larger world." Given this information, it is not surprising that Jeffrey left his placement with a self-described appreciation for the significance of his research.

Other students seemed to think that their research held some significance but did not talk about this importance in concrete terms; these students were assigned a rating of medium. Sarah, for example, discussed her research as being important but was unable to provide details in terms of why the research was significant or ways in which it might be used or applied. Students in this category may have understood what sorts of results they might obtain through their research but could not or did not elaborate on the value of these results in a context broader than their own laboratory. Finally, some students openly discussed their research as lacking significance or acknowledged that they did not understand why the findings might be important. These students were assigned a rating of low in this category. Rachel, for example, said, "I understand what's going on as far as what we're doing, but I don't see the purpose of it. Like the main purpose."

Interest in Project

The final experience variable that emerged was the amount of interest that students expressed in their research. Some students clearly expressed strong interest in the research they were conducting. This interest often was attributed by the students to their ability to self-select a laboratory placement within a field of science in which they were already interested. For example, Danielle said, “I got exactly what I wanted” when discussing her project. Hector discussed initial interest in his project and becoming even more interested as he learned about the science involved: “I saw what was in the water and stuff and different organisms and started learning about them, so it became a lot more interesting.”

Other students described being uninterested at the beginning of the experience but developed a moderate level of interest as the project progressed. These students were assigned a rating of medium in this category. Claudia offered sentiments similar to several of her peers in the following: “I got used to it [the research topic], and I don’t really think it’s not interesting anymore.” Students were also assigned a rating of medium in this category if they presented conflicting views on their levels of interest. These students stated that they were interested but went on to describe how the project was dull and boring. Only one student was given a rating of low in this experience variable. Roberto was displeased with his placement. He was not in an area of science that he found interesting and as a result found his specific project to be uninteresting.

Student ratings for all of the experience variables are presented in Table 3. It should be noted that we did not feel as though data collected from one student in the 2007 cohort, Mary, were informative enough to warrant a rating in the *Result Significance* category.

Table 3 Student experiences and NOS ratings

Student	Experience Variables					Outcome Variable
	Mentor Support	Collaboration	Epistemic Involvement	Result Significance	Interest	NOS
1.Gabriela	M	H	M	H	H	H
2.Hector	H	H	H	M	H	H
3.Beth	H	H	M	H	M	N/A
4.Jessica	M	H	M	H	H	N/A
5.Rachel	L	L	M	L	M	N/A
6.Vlad	H	H	H	H	H	H
7.Amy	H	H	L	H	H	N/A
8.Mary	H	H	M	N/A	H	H
9.John	M	L	M	L	M	M
10: Claudia	M	L	L	H	M	L
11: Roberto	H	H	L	L	L	M
12: Danielle	H	H	H	L	H	M
13:Stephanie	M	H	H	H	M	M
14: Patrick	H	H	L	H	H	H
15: Jeffrey	H	H	M	H	H	H
16: Sarah	H	H	M	M	M	M
17: Jenny	H	H	M	M	H	M
18: Mike	H	H	M	M	M	M

H = High. M = Medium. L = Low. N/A = No rating assigned.

Variation in Student Outcomes

Whereas each of the experience variables was assigned ordinal ratings, only one of the outcomes lent itself to this type of analysis. Students' NOS understandings were assigned ratings (low, medium or high), and these ratings are summarized in Tables 2 and 3. Variation in the two other outcome variables (content knowledge and future science plans) was analyzed differently. Science content knowledge was assessed through analyses of the evolving concept maps. Future science plans were examined by analyzing student responses to interview questions at the beginning and end of the experience and by tracking how participants' future plans shifted over time.

Nature of Science

In the first year of the study, student ideas about the nature of science emerged from their responses to open-ended interview questions about their research and what they were learning. Some of these students commented on their understandings of the tentativeness of science and the social nature of scientific knowledge generation. Based on these findings, we integrated a question that challenged students to reflect on how scientists work and how their experiences had influenced their ideas about how scientists work. All of the students from the 2008 cohort responded to this item and offered comments reflective of their ideas about some aspects of NOS.

The data revealed differences in student understandings of some NOS aspects that developed throughout their apprenticeship (Tables 2 & 3). Based on the available data, we focused specifically on student understandings of the tentativeness of science knowledge, the social nature of knowledge generation and the creativity involved in scientific practices. Students who articulated sophisticated ideas relative to these aspects of NOS were rated high in the NOS category. Students who expressed a mixture of naïve and sophisticated views on NOS aspects were assigned a rating of medium, and students who only expressed naïve ideas on NOS were assigned a rating of low in this category.

Six students expressed sophisticated ideas when they discussed NOS themes. Four of these students participated in the 2007 program when the interview protocol did not specifically ask for them to reflect on how scientists work. Patrick represented this group well. He talked about how his understanding of science changed throughout the experience. At the beginning, he thought that science was about following stepwise procedures. According to him, it was about "how to be smart in lab, don't do anything dumb." He said that he didn't want to do research at the beginning of the program because science was "like a boring fact". As the apprenticeship experience progressed, however, he grew to understand science as a continuously evolving process. He talked about science as "an alternate way to get an alternative point of view". These brief comments were indicative of Patrick's more extensive remarks and actions that demonstrated his understanding of science as a process involving fluid methods, ingenuity, and creativity. Mentor data corroborated these interpretations in that Patrick's mentor discussed how research apprenticeships should ideally influence student understandings of NOS. The mentor reported that the experience "opens their [students'] eyes up to what science is really like". He continued to describe science as being "very open-ended with a lot of fuzziness. So I think it is a good idea for them [students] to see what it's like and also see what the culture of a lab can be like."

Other participants offered a mixture of naïve and sophisticated views of NOS. For example, Mike described research as being conducted through a process of procedural redundancy. He did not seem to understand science knowledge as being in a process of continual change. Mike held the notion that scientific knowledge exists and if scientists follow the scientific method, then they will find this verifiable truth. However, Mike also discussed the results of his specific project as being in a process of refinement. He discussed the evolving nature of his work in computer science indicating that researchers would never develop “the perfect program.” This comment was indicative of Mike’s developing understanding of a tentative nature of science, but he never fully abandoned his absolutist view on the nature of scientific knowledge. John was another student who seemed to hold a mixture of NOS views. When talking about research, he discussed a process of knowledge construction involving multiple parties in competition and collaboration building toward better understandings of natural phenomena. However, as he discussed his own work, it was clear that he had a relatively naïve view of the certainty of science knowledge and the pursuit of “correct” results.

Only one student expressed consistently naïve views on NOS aspects by the end of the experience. Claudia believed that science research was an activity that consisted of “proving” what had already been established as truth. She seemed to think that proving knowledge was conducted in a stepwise procedure (i.e., through *the* scientific method). If one part of this procedure was missed, the researcher had to go back and repeat the whole process. She talked of her own work as a process of repetitive tasks. Additionally, when Claudia discussed the work of a scientist, she talked about it as a solitary endeavor without opportunities for social negotiation of ideas. She discussed the isolation of a scientist as “a choice they made for their life.” Claudia’s experience of professional science in this particular context seemed to negatively influence her personal understandings of NOS and as a result she grew disinterested in science.

Science Content Knowledge

Interview data revealed that all of the students believed that they learned science content over the course of the experience. This was revealed in quotes such as “I’ve learned a lot about what we’re doing, stem cells” (Stephanie) and “I learned a lot about the immune defenses in the brain” (Jenny). These data were supported by a general increase in complexity and detail in student discussions of science content relative to their projects. The excerpts below were taken from interviews with Claudia at the beginning and end of the experience.

> We're getting different tissues of corn, like the kernels the ovaries and what we're doing is checking if they can find, we can find the enzyme EGP in the kernel and different tissues that we get of corn and we're seeing how much of it there is in every tissue to see if that enzyme comes up on the endosperm, before fertilization or after fertilization. (Claudia, 1st interview)

> I discovered that I was going to be working with corn and I was going to be looking at the expression of the enzyme EGP and the subunit SH2 in the corn tissue, in the different tissues. Especially in the endosperm which is located in the kernel of the corn and overall what we saw at the end of the 7 weeks was that expression is mainly in the endosperm, it's not found in any other tissue. No cobs or no ovaries. We also saw that the 18-day post pollination was the one with the most activity of EGP, so therefore the more time after fertilization, in the endosperm, the more activity we'll find of EGP. And what we saw with that was for us to do, like for us to build a model of this enzyme. We would need the activity would just increase with the most time

> and it would just only be seen in that specific area. And yeah, the research is still going to continue because we have to see if the enzyme is now found in the silks of the corn and if they can be also located in the tips of the kernels, because of the idea that the corn grows from the root to the top so maybe in the tips they have more concentration EGP than in the center of where we were looking at. (Claudia, 2nd interview)

In the first quote, Claudia was able to provide a limited summary of her project. In contrast, Claudia's comments at the end of the experience provided a more detailed accounting of her research. Claudia's mentor expressed the following: "For a high school student, I think she had a wonderful grasp of what she was doing." This trend of increased capacity to describe one's work and the scientific concepts related to that work was observed among all of the participants.

Concept Maps

Students in the 2008 cohort created concept maps at the beginning and end of the experience. Two students' maps were not analyzed. Jeffrey changed research projects after creating his first concept map, and Jenny did not create an initial concept map as a part of her first interview. We assessed multiple dimensions of each student concept map including structure and numbers of labeled links, concepts and discipline-specific concepts.

Figures 1 and 2 present concepts maps created during Roberto's first and third interviews respectively in order to demonstrate our analytic approach. In Roberto's first concept map,

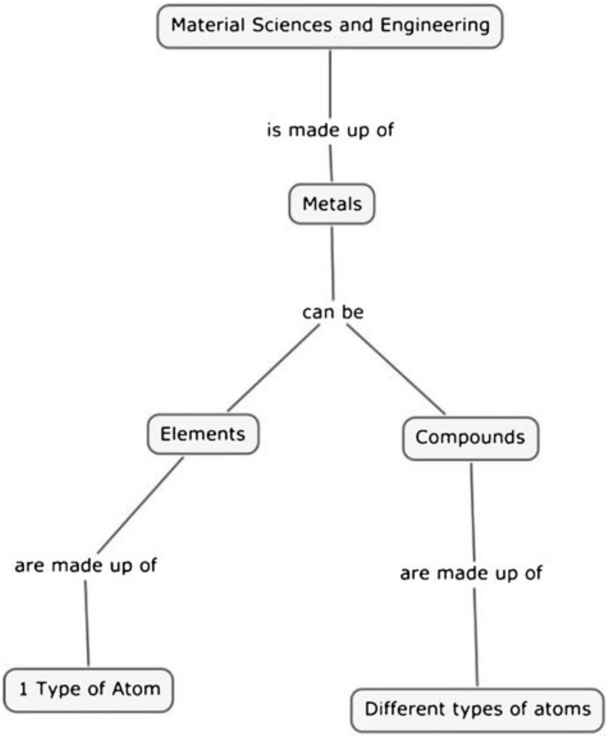

Fig. 1 Roberto's concept map A. This concept map was created at the beginning of his research apprenticeship

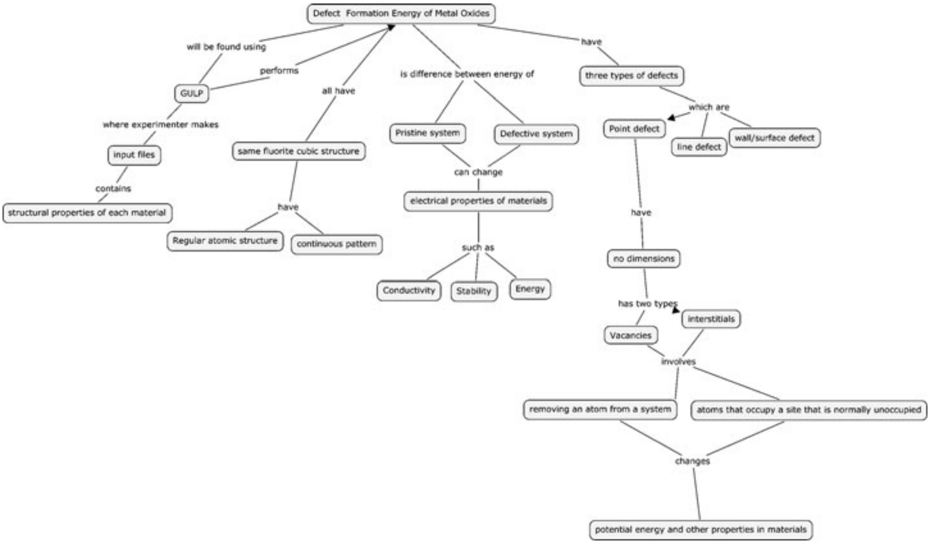

Fig. 2 Roberto's concept map B. This map was created at the end of his research apprenticeship

we counted 4 link labels and 6 concepts, but none of these concepts were labeled as discipline specific concepts. This map was categorized as a tree structure. In Roberto's second concept map, he presented 15 labeled links, 23 concepts, and 10 discipline specific constructs. This map was categorized as being a network/net structure because of multiple

Table 4 Concept map analysis

Student	Concept Map	Structure	Link Labels	Concepts	Discipline Specific Constructs
10: Claudia	A	Hub/Spokes	9	12	6
	B	Tree	11	16	8
11: Roberto	A	Hub/Spokes	4	6	0
	B	Network/Net	15	23	10
12: Danielle	A	Tree	7	8	5
	B	Network/Net	14	14	9
13: Stephanie	A	Tree	9	15	12
	B	Network/Net	21	27	20
14: Patrick	A	Linear	5	6	4
	B	Tree	9	10	6
15: Jeffrey*	A	Tree	19	20	13
	B'	Tree	14	15	10
16: Sarah	A	Tree	3	7	5
	B	Linear	9	11	8
17: Jenny+	B	Tree	13	15	13
18: Mike	A	Network/Net	8	17	12
	B	Network/Net	9	18	13

A = Concept Map created towards the beginning of the program. B = Concept Map created towards the end of the program. * = Concept Map A and B' are related to two different projects. + = Only one Concept Map for this student.

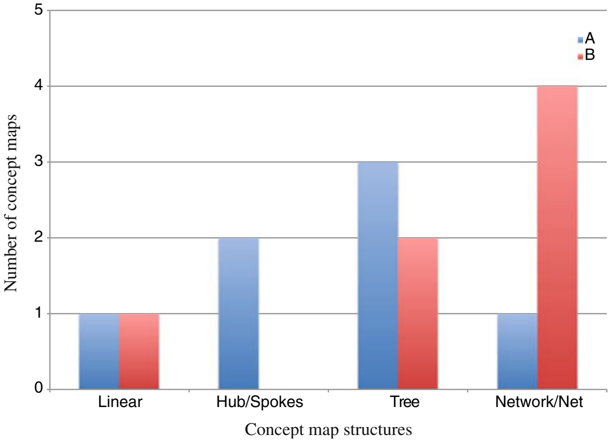

Fig. 3 Total count of participant concept map structure types at each stage of the authentic research apprenticeship. A = beginning of the experience. B = end of the experience

linkages among concepts. Table 4 displays concept map structure and the numerical counts of labeled links, concepts, and discipline specific constructs for all participants. Figure 3 provides a graphic depiction of how the concept map structures changed over time. Figure 4 offers a graphic representation of changes in the numbers of link labels, concepts, and discipline specific concepts over time.

Concept map structures became more complex for five of the seven participants included in the analysis. Mike's first and final maps were categorized with the highest level of complexity (net/network). Sarah was the only student to create a final concept map that demonstrated less complexity than her initial map. The number of labeled links, concepts and discipline specific constructs increased from the earlier to the later concept maps for all of the students including Sarah whose map decreased in complexity. This multi-faceted

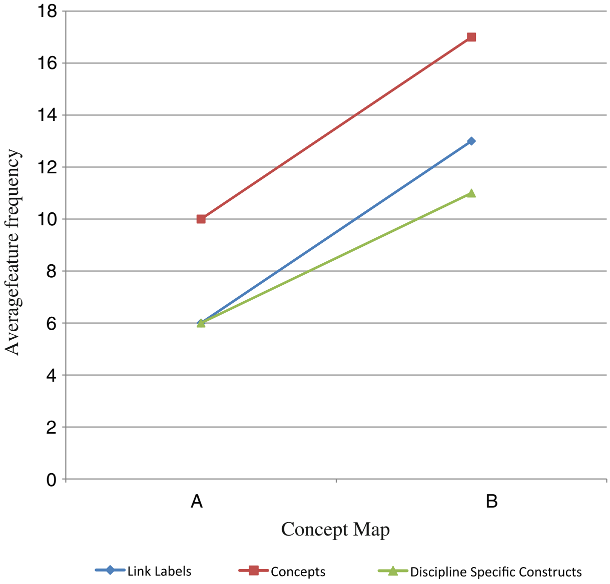

Fig. 4 Average counts of link labels, concepts, and discipline specific constructs at each stage of the authentic research apprenticeship. A = beginning of the experience. B = end of the experience

approach to assessing the concept maps provided evidence that the students left the project with more robust understandings of the science content associated with their projects as compared to their initial understandings.

Future Science Plans

Information on the students' future science plans (i.e. college majors and careers) was available for 16 of the 18 participants, because two students (Stephanie and Jenny) did not respond to the career-related questions. Students were assigned to one of four groups. At the beginning of the experience, two students expressed a desire to pursue careers in research science, operationalized as a career in science that prioritized knowledge generation such as a science faculty position in an academic institution. Five students described their desire to participate in an applied science. These students wanted to be engaged in science but preferred fields in which they would use science but not necessarily contribute to research. For example Jessica wanted to be a pharmacist and Mary wanted to be a dentist. Five other students expressed a general interest in science. They knew that they wanted to major in science and/or pursue a science related career, but they did not have a specific scientific field or career in mind. Four students knew coming into the experience that they did not want to pursue a future in science.

By the end of the experience four of the participants had modified their future plans with regard to science. The ways in which participants altered their plans are depicted in Fig. 5. Of the 12 participants who did not modify their future plans, two maintained their interest in research science careers and three still desired to pursue a career in applied science. Three of the five individuals who were originally interested in science but unsure of

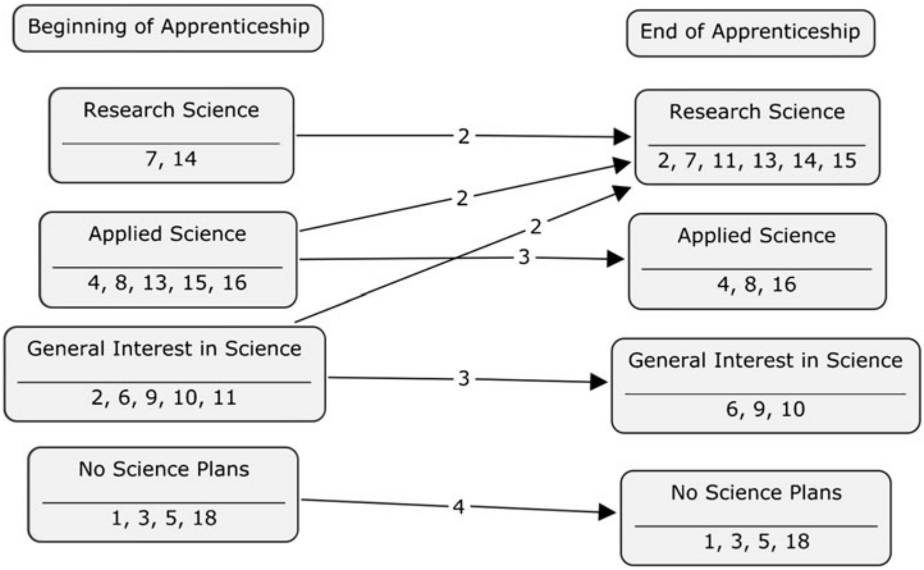

Fig. 5 Future science plan shifts from beginning to end of the authentic research apprenticeship. Numbers underneath each category are the student numbers from Table 1. Numbers on the arrows represent the number of students who along that path from the beginning to the end of the apprenticeship

specific courses of study or career paths maintained their ambivalence. All four of the participants who came into the program not interested in science for their careers left the program with similar ideas.

Changes occurred among students in the groups originally interested in applied science or having a general interest in science. Four students from these groups developed new interests in pursuing research science. Stephanie for example entered the program with a desire to become a practicing physician; by the end of the program she wanted to become a physician-researcher. Jeffrey also wanted to pursue science in his future but was uncertain about specific paths. By the end of the program, his ideas about possible areas of study were clearer and he expressed a commitment to scientific research as an undergraduate. He even commented that opportunities for undergraduate research would be a factor in choosing a college.

In contrast to these students, others from the applied science group and the general interest in science groups described why they had not become more interested in pursuing careers involving scientific research. Claudia was the most outspoken about this as demonstrated in the following interview excerpt: “I am positive that I really don’t like research, and like I know that this is not for me.” Sarah, who entered the program with a desire to become a dentist, also discussed becoming less interested in science research: “[the experience made me] “a little less interested (in science) to be honest;” however, she still indicated a desire to become a dentist.

All mentors discussed the impact of the program on the plans of their students. The mentors felt strongly that the experience helped students better understand options for pursuing scientific study and careers. Patrick’s mentor said, “He couldn’t believe how much he learned … and he could actually see himself doing this kind of thing [scientific research] as an undergrad.” Whereas Patrick and Jeffrey’s mentors expressed ideas consistent with their students, Claudia and her mentor offered very different ideas. For Claudia, the experience eliminated any possible interest in scientific research, but her mentor reported that she “enjoyed research enough that she might want to actually pursue research a little bit. It was really good for her I think.”

Summary of the Variations in Student Outcomes

Little variation was observed in the content knowledge construct. Interview and concept map data indicated that participants learned science content as a result of their experiences. More variation was seen in the NOS and future science plan constructs. We observed students demonstrating sophisticated, naïve and intermediate ideas about the tentative, social and creative aspects of science. In terms of career plans, four students became more interested in pursuing scientific careers. The other students showed no changes in their future science plans.

Relationships between Participant Experiences and Outcomes

The second research question called for an examination of possible relationships between participant experiences and outcomes. In order to investigate these, we looked for patterns in the variation documented through qualitative analyses of the variables. Given the nature of the study and the limited number of participants, these findings are necessarily limited in terms of their generalizability. In the sections below, we discuss associations between experience variables and NOS and future science plan outcomes. Because of the lack of variation in content knowledge growth, this outcome was not included in the analysis.

Experience Variables & NOS

To look for potential relationships among the experience variables and NOS, we examined data from students rated as either high or low on NOS (see Table 5). If an experience variable was directly related to NOS ideas, we expected to see consistent patterns across the experience variables for all of the individuals in either of the NOS groups. The fact that only one student was in the low group significantly limited the conclusions that could be drawn from these analyses; however, some interesting trends did emerge. For example, all of the high NOS students expressed high levels of collaboration and interest. In contrast, the single low NOS student had low levels of collaboration and moderate interest in her project. This suggested that interest in one's research and participation in a collaborative research environment may be related to an apprenticeship participant's development of NOS ideas. All of the students in this analysis were rated as expressing high or medium appreciation for the significance of their research results (except Mary whose data relative to this variable were missing). Because students with low and high NOS outcomes had high result significance ratings, it appeared unlikely that this was a significant mediator of NOS understanding. The same basic argument could be applied to the mentor support variable. The epistemic involvement variable offered an interesting case in that individuals within the high NOS group demonstrated variable epistemic involvement. This pattern suggested that epistemic involvement was not necessarily associated with the NOS variable.

Experience Variables & Future Science Plans

Table 6 compares future science plan outcomes with each of the five aspects of the apprenticeship that were investigated. This table only includes students who made positive changes in the future science plan over the course of the experience and those who made no such positive change but potentially could have done so. We made the determination that a move towards an interest in a research related science future was a positive change that was desirable based on the intended purposes of the program being investigated. It should be noted that students who declared interest in science research at the beginning and end of the program were not included in this analysis because they had no possibility for making a positive change.

Table 5 Experiences shaping nature of science (NOS)

Student	Mentor Support	Collaboration	Epistemic Involvement	Result Significance	Interest
Students Rated High in NOS					
1. Gabriela	M	H	M	H	H
2. Hector	H	H	H	M	H
6. Vlad	H	H	H	H	H
8. Mary	H	H	M	N/A	H
14. Patrick	H	H	L	H	H
15. Jeffrey	H	H	M	H	H
Students Rated Low in NOS					
10. Claudia	M	L	L	H	M

H = High. M = Medium. L = Low. N/A = No rating assigned.

Table 6 Experiences shaping future science plans

Student	Mentor Support	Collaboration	Epistemic Involvement	Result Significance	Interest
Positive changes in future science plans					
2.Hector	H	H	H	M	H
11. Roberto	H	H	L	L	L
13.Stephanie	M	H	H	H	M
15. Jeffrey	H	H	M	H	H
No changes in future science plans					
1.Gabriela	M	H	M	H	H
3.Beth	H	H	M	H	M
4.Jessica	M	H	M	H	H
5.Rachel	L	L	M	L	M
6.Vlad	H	H	H	H	H
8.Mary	H	H	M	N/A	H
9.John	M	L	M	L	M
10. Claudia	M	L	L	H	M
12: Danielle	H	H	H	L	H
16: Sarah	H	H	M	M	M
17: Jenny	H	H	M	M	H
18: Mike	H	H	M	M	M

H = High. M = Medium. L = Low. N/A = No rating assigned.

All students who showed positive changes participated in collaborative environments suggesting that collaboration may be a factor related to how the experience affected participant ideas about future science plans. Epistemic involvement did not seem to be a contributing factor in that wide variability in this construct was evident in students exhibiting positive changes to their future science plans as well as those that did not. The observation that Roberto exhibited a positive change in future science plans while being the only student rated low in interest in the research project itself was surprising. Roberto explained this observation when he elaborated that although he did not care for his research project topic or lab placement, he grew to enjoy research and wanted to participate in it in the future.

Discussion

We observed individual variation across all experience variables identified: interest, mentor support, collaboration and epistemic involvement. These findings document student variation within a common program. This is an important result because many studies of similar programs take a holistic approach and fail to account for the variety of individual participant experiences (Sadler et al. 2010). Variation was also seen in the outcomes associated with student participation in this apprenticeship program. We detected the least amount of variation in student content knowledge; all students demonstrated some gains in content knowledge associated with their research. The limited variation may be attributed to our data collection methods and our ability to tease apart potential differences. Having said that, we feel confident that the data do support the conclusion that participants learned significant science content through this experience.

In regards to the impact of this program on future college and career plans, the variation observed seemed to be in line with previous research which indicates that participants in these types of experiences tend to be already committed to future science plans and that research apprenticeships impact those plans minimally (Lopatto 2004). In this study, the students who were firmly committed to research science at the beginning of the program were likewise committed at the end of the program. Similarly, the four students who were not committed to science, left the program with the same low level of commitment to a science related future plan. However, some positive impacts were observed with students with a general interest in science or an interest in applied sciences. For students who are already interested in science at the beginning of the program, a research apprenticeship may offer an opportunity for enrichment and/or clarification of future plans. Variation was also seen among student understandings of the nature of science.

In our examination of the relationship between individual experiences and desirable student outcomes we noted that both collaboration and interest were potentially positively related to student understandings of NOS. Claudia's case provided the most apparent demonstration of this. Her experience was one of loneliness and isolation. Claudia described development of the idea that science was an endeavor best suited for introverts. Most of the other student participants felt that they became part of a research team. Even in the cases where a student did not have much contact with a faculty mentor, graduate students provided mentorship. This collaboration seemed to also be linked to students' future plans. All four students who reported an increase in a desire to participate in research-based science in the future experienced a high level of collaboration in their placements. Student interest also seemed to be an aspect that helped shape understandings of NOS. When examining students who exhibited the strongest interest in their research project, it became evident that these students had been placed in a laboratory that was researching an area of science that they self-selected.

An interesting finding was that epistemic involvement of students did not seem to be related to the NOS understandings or changes in future science plans. Data from Patrick and his mentor shed important light on this issue. The mentor discussed his belief that high school students did not have adequate backgrounds in research methodology or the time necessary to be involved in the posing of research questions and the design of procedures. In fact, none of the students in this research were involved in the initial design of research questions. However, some of them were working on original research and had opportunities to provide input in the process of its development. Patrick, though, was working on a research project that had been previously done and had known results. Despite this situation, Patrick exhibited some of the most positive outcomes of any of the nine students. This seeming lack of correlation between epistemic involvement and student outcomes contradicted other reports that have stressed the significance of epistemic involvement (Ryder and Leach 1999; Sadler et al. 2010).

Implications for Design and Implementation of Apprenticeship Programs

In this study, we have used qualitative methods to document student experiences and outcomes associated with an apprenticeship program. These methods allowed for an in-depth exploration of experiences and outcomes but they limited the number of students with whom we were able to work. It is also important to note that the findings stem from students in only one program. These issues necessarily limit the generalizability of results. As with most qualitative work, the extent to which findings are *transferable* to other contexts is a decision best made by individuals familiar with other contexts (Lincoln and Guba 1985). While we certainly do not claim that the patterns that emerged in this setting will hold for all apprenticeship programs, we do think that the conclusions provide some possible considerations for those who plan and implement apprenticeship experiences for secondary students.

One of these considerations is the issue of student interest in the projects to which they contribute. One strategy for promoting interest is to prioritize student choice in the process of assigning students to laboratory placements. Of course, this recommendation may be at odds with institutional or programmatic constraints that limit student choice. We recommend that program designers at least provide opportunities for participants to share their interests. The students we surveyed had more positive attitudes towards their research when they felt like an effort had been made to place them according to their desires. Related to this, our findings suggest that individuals already interested in science stand the most to gain from apprenticeship opportunities. It seems unlikely that programs like the one investigated here will be successful at making scientists out of students who are uninterested at the outset of the program.

Another consideration highlighted by our results is the collaborative nature of the laboratory environments into which students are placed. We recommend a mentor screening process that involves collecting information related to frequency of lab group meetings, the makeup of lab groups and the roles played by graduate students and others within the lab group. Program implementers may want to avoid placing participants with mentors who work in isolation. Our results suggest that students not participating in a collaborative research group may leave an apprenticeship program with naïve views about the social aspects of science knowledge generation.

Although our findings indicate that epistemic involvement was not a mediator of desired student outcomes for this sample of students, we recommend that mentors explicitly engage their students in the rationale for such limited involvement. We base these recommendations on the relationship that existed between Patrick and his mentor. Both Patrick and his mentor clearly expressed why the student's epistemic involvement needed to be limited in the context of this experience. This issue was an explicit topic of their conversations, and Patrick benefitted from understanding why his involvement was limited. If a student is entering a research project that is already in existence, the mentor could provide the student with the history behind the generation of the research questions and the subsequent design of methods and experiments. In this way, the student could still come to appreciate the creativity and innovation underlying scientific research even if time constraints make it impossible for them to experience these aspects first hand.

Implications for Future Research

Although this research documented science content growth, a more nuanced approach to the collection of content knowledge data and analysis of those data may reveal a level of variability beyond that which was detected in this study. One possibility for doing so could involve mentor assessments of the quality of the content represented in participant concept maps or other knowledge representations. Also, each of the students in this study were highly achieving in science and mathematics. Further investigations of students less accomplished in science and mathematics but still interested in science may yield different results. Work could also be conducted using a more formal approach to the assessment of student understandings of NOS. For example, Roberto seemed to be conflicted with his understandings of NOS in the context of his specific laboratory placement and in the context of science more formally. Sandoval (2005) suggests a relationship between students' formal and practical epistemologies of science. Future research could examine this interplay between formal and practical epistemologies of students participating in research apprenticeships. These results also suggest a potential link between explicit discussions of epistemic involvement and understandings of NOS. Future research should examine this interaction in greater detail. Additional research which involves following students longitudinally as they return to their high schools (e.g., Stake and Mares 2005) or, if possible, later when they actually enact college and career decisions would provide a degree of insight that heretofore has not been available.

Appendix A: Participant Semi-Structured Interview Protocol

(The codes following each question identify when each prompt was used: 7=2007 cohort; 8=2008 cohort; A=first interview; B=second interview; C=third interview)

- Tell me about yourself? Where are you from? What are your interests? What do you do for fun? [8-A]
- What kind of "science experiences" have you had prior to participating in SSTP? (e.g., science camps, internships, parent is a scientist, science fair, etc.) [7-A, 8-A]
- What kind of science courses have you taken in high school? Do you feel that these courses have prepared you for SSTP? [7-A, 8-A]
- Why did you want to come to SSTP? [7-A, 8-A]
- What are your plans after high school?

  If you are going to college, what would you like to study?
  What professions are you considering?
  Do you see yourself studying/doing/participating in science in any way? [7-A, 7-B, 8-A]

- Can you tell me some about work that you are doing as a part of SSTP?

  What kind of research goes on in the lab that your are working in?
  What have you done in the lab so far?
  Describe the project(s) that you are working on?
  What kinds of lab processes and/or equipment are you using?
  Do you find this work interesting? [7-A, 7-B, 8-A, 8-B, 8-C]

- Do you work directly with a faculty member? If so, in what ways do you work with the faculty member?

  Are you working with graduate students and/or post-docs?
  Do you work with other high school researchers or undergraduates?
  Who is helping you figure out how to do scientific research? [7-A, 7-B, 8-A]

- How do you feel about your abilities to work in the lab?

  Is this really easy work that is not challenging you?
  Do you feel that you've been well prepared to do the work you are doing?
  Do you have a good understanding of the science content you are investigating?
  Do you feel comfortable using the equipment and procedures of the lab you are working in?

Do you see yourself as a working contributor in the lab, an outsider just visiting, or something in between? [7-A, 7-B, 8-A, 8-B, 8-C]

- How has your comfort level in your lab environment changed since we last spoke? [8-B]
- What kind of progress are you making on your research project? How far has your project come since we last spoke? [8-B]
- What sort of data have you collected so far? Have you completed any analyses to make sense of these data? If so, what have you found? What do your preliminary results mean? [8-B]
- What have you learned about the science related to your research topic? [8-B]
- Describe the relationships that you have developed with other people in your laboratory. Who has helped you learn how to work in the lab? [8-B, 8-C]
- Have you had any role in determining the kind of research that you are doing?

Are you working on someone's pre-existing project? [7-A, 7-B, 8-A, 8-C]

- How does what you are doing match up with the expectations you had before you got here?

Are you studying areas of science that you wanted to look at?
Did you expect the kind of work load that you have? Are you doing more or less work than you expected? [7-A, 7-B, 8-A, 8-C]

- Are there any ideas or tasks, particularly in the lab that you are confused by or struggling with? [7-A, 7-B , 8-A, 8-C]
- Please describe your findings. What do these findings mean? How can they be applied? [8-C]
- How has this experience affected your understandings of how scientists work? [8-C]
- SSTP has several things going on outside of your research lab like the morning lectures and the research seminar. Do any of these stand out for you as important elements of your experience? [7-A, 7-B]
- Do you work directly with a faculty member? If so, in what ways do you work with the faculty member?

Are you working with graduate students and/or post-docs?
Do you work with other high school researchers or undergraduates?
Who is helping you figure out how to do scientific research? [8-A]

- Has this experience made you more or less interested in science?

More or less interested in going to college?
More or less interested in majoring in science in college?
More or less interested in pursuing a career in science? [8-C]

- Do you have any other thoughts you'd like to share about your own work as a scientist or the research that you are doing? [7-A, 7-B, 8-A]

Appendix B: Mentor Semi-Structured Interview Protocol (Summer of 2008)

1) How many years have you been hosting an SSTP student in your lab?
2) What factors led to you deciding to be a mentor to these students?
3) Did you work directly with the student this summer?

4) If not, who did?
5) Can I get their contact information so that I can interview them?
6) In what role did you work with this summer's student?
7) To what degree did the student take ownership of his or her project?
8) Did you observe any changes in the student over the course of the summer? If so, in what ways?
9) Did the student seem to feel comfortable working with your lab group?
10) Would you say that the student felt like a working contributor in the lab, an outsider just visiting, or somewhere in between?
11) In your estimation, what were the reasons for such student positioning?
12) Did the student express any interest in pursuing a science related major and/or career?
13) How do you think the opportunities afforded to the student in your lab this summer will help with their future science plans?

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